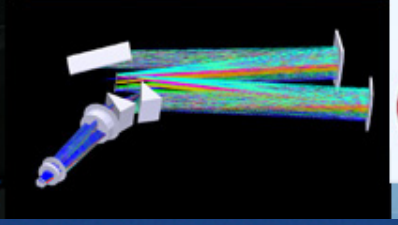


山东大学（威海）
SHANDONG UNIVERSITY，WEIHAI


Blazar Variability Research and Observations by Weihai one Meter Telescope

Shao Ming Hu（胡紹明）
Institute of Space sciences, Shandong University at Weihai

Dec. 4, 2017, Kagoshima, Japan

Outline

- Motivation
- Brief introduction to Weihai observatory
- Blazar observations and variability research

Blazars

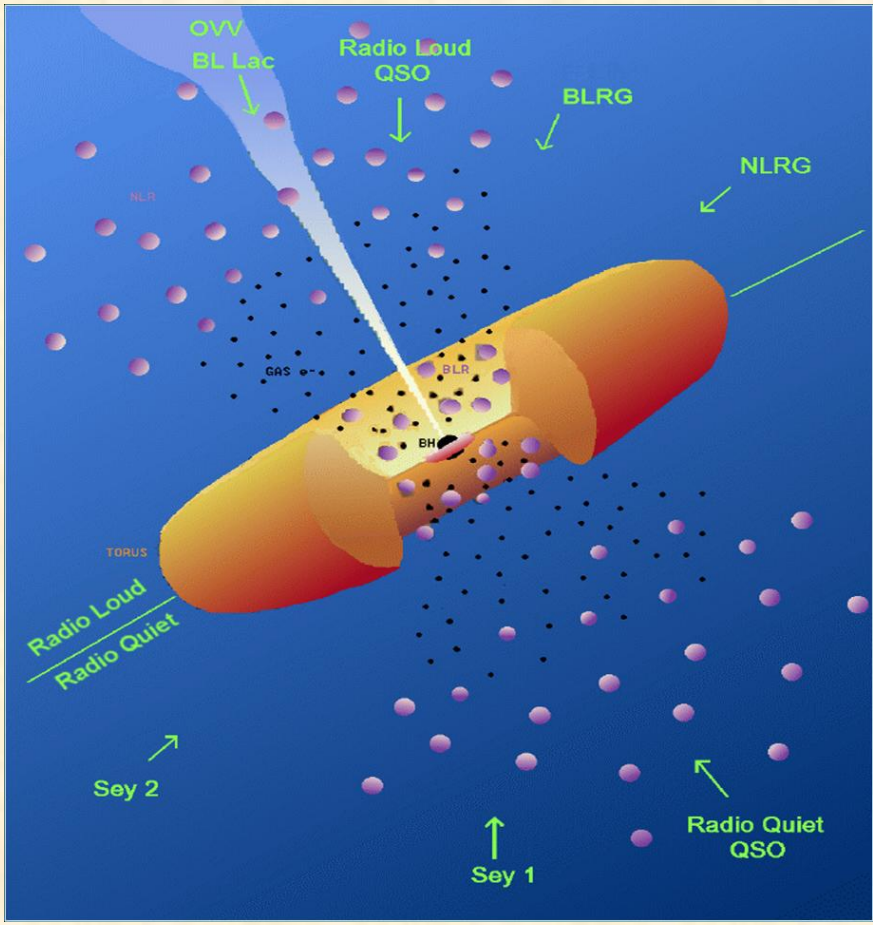
- Defined by 1) strong variability (minutes to years) from radio to γ-rays and high polarizations (1-4%)
- Moderate to strong radio sources (radio loud)
- Two classes:

1) BL-Lac objects: no strong emission or absorption lines

- likely beamed FR Is

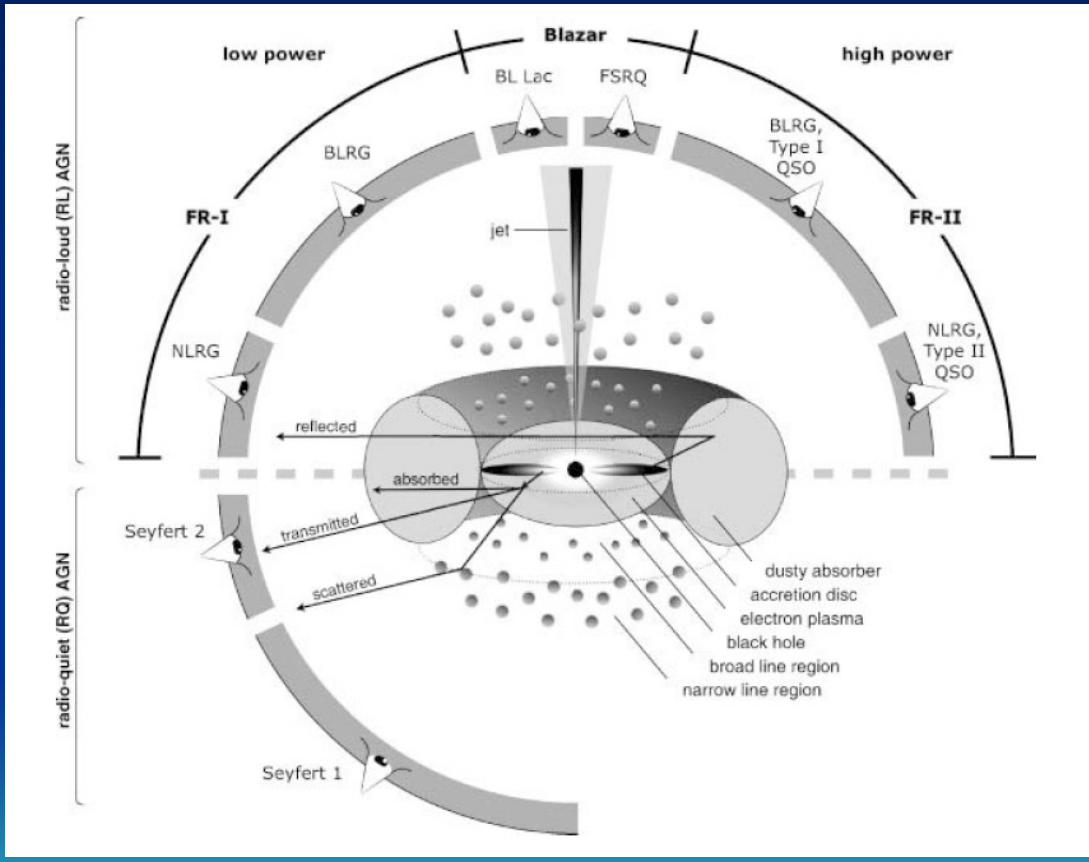
2) Optically-violent variables (OVVs): highly polarized, variable, but have broad emission lines like quasars

- likely beamed FR IIs



Research Motivation

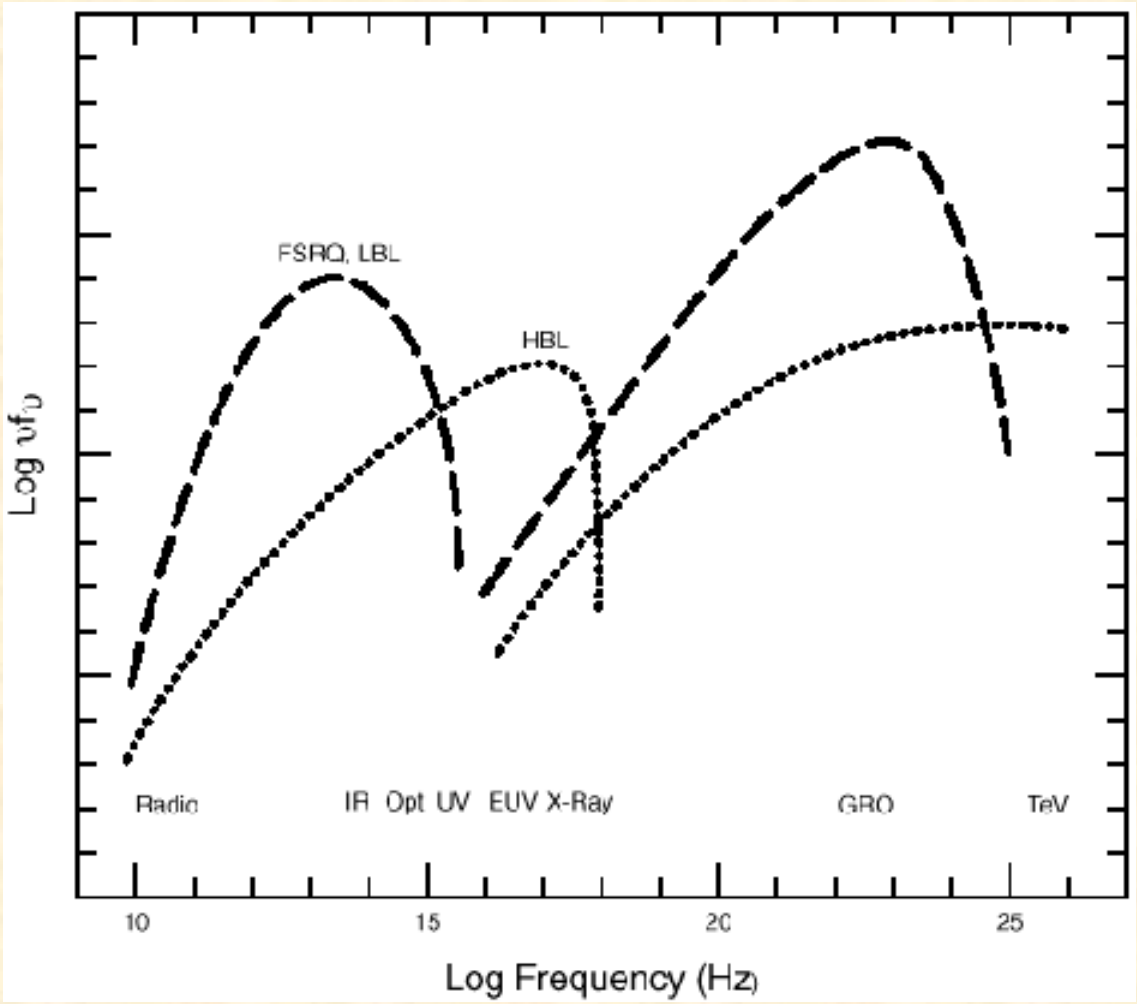
- The structure of BH, Accretion disk, BRL etc within pc can not be observed directly. Varibility is an important method to research the central structure and physcial process of AGN;
- Blazar is a natural lab to research the physics of jet;
- The origin of blazar variability is still a open question. More observational properties is needed to understand the origin and physics of AGN variability.



(Netzer 2015, ARA&A, 53, 365; Wagner & Witzel 1995, ARA&A, 33, 163; Ulrich et al. 1997, ARA&A, 35, 445; Falomo et al. 2014, A&ARv, 20, 73)

Blazar SEDs (Urry 1998)

Synchrotron | Inverse Compton

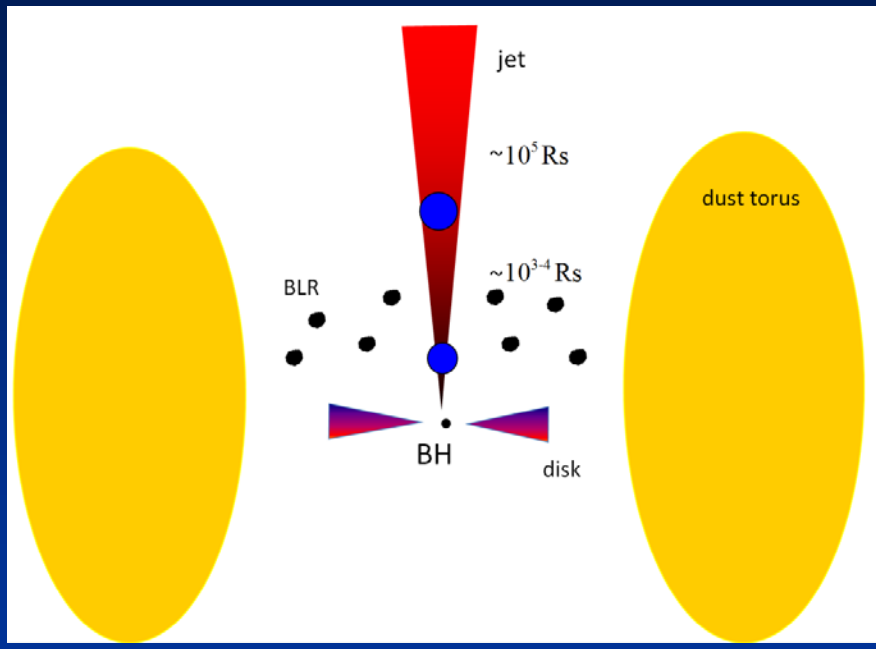


Inverse Compton Models:

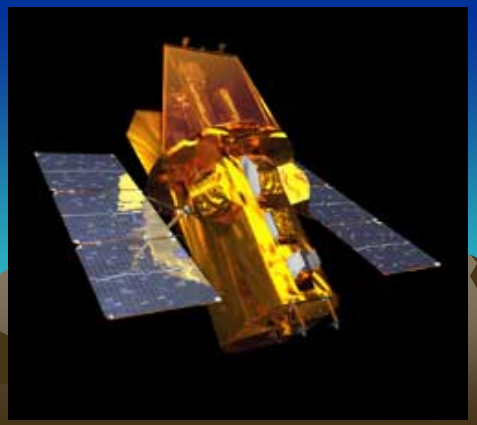
- Syncrotron Self Compton (SSC)
- External Compton (EC): seed photons from accretion disk, BLR, Cosmic Microwave Background (CMB), etc.

Research Motivation

- Blazar has radiation across the complete electromagnetic spectrum. Multiband variability properties and information are probes to understand the central structure, energy origin and mechanism, jet physics etc.;
- It's possible to research by multiband information due to open Radio, IR, optical, SWIFT, Fermi etc. data.








Observational research on variability properties

Observation analysis

Variability properties

- Spectra variability
- Microvariability properties
- Variability symmetry
- Periodic variability, the time scale, energy of flares……

Variability origin and physics

- Constrain the radiation mechanism
- Provide physical parameters for physical models
- Constrain the physical process and accrelation mechanism in jet……

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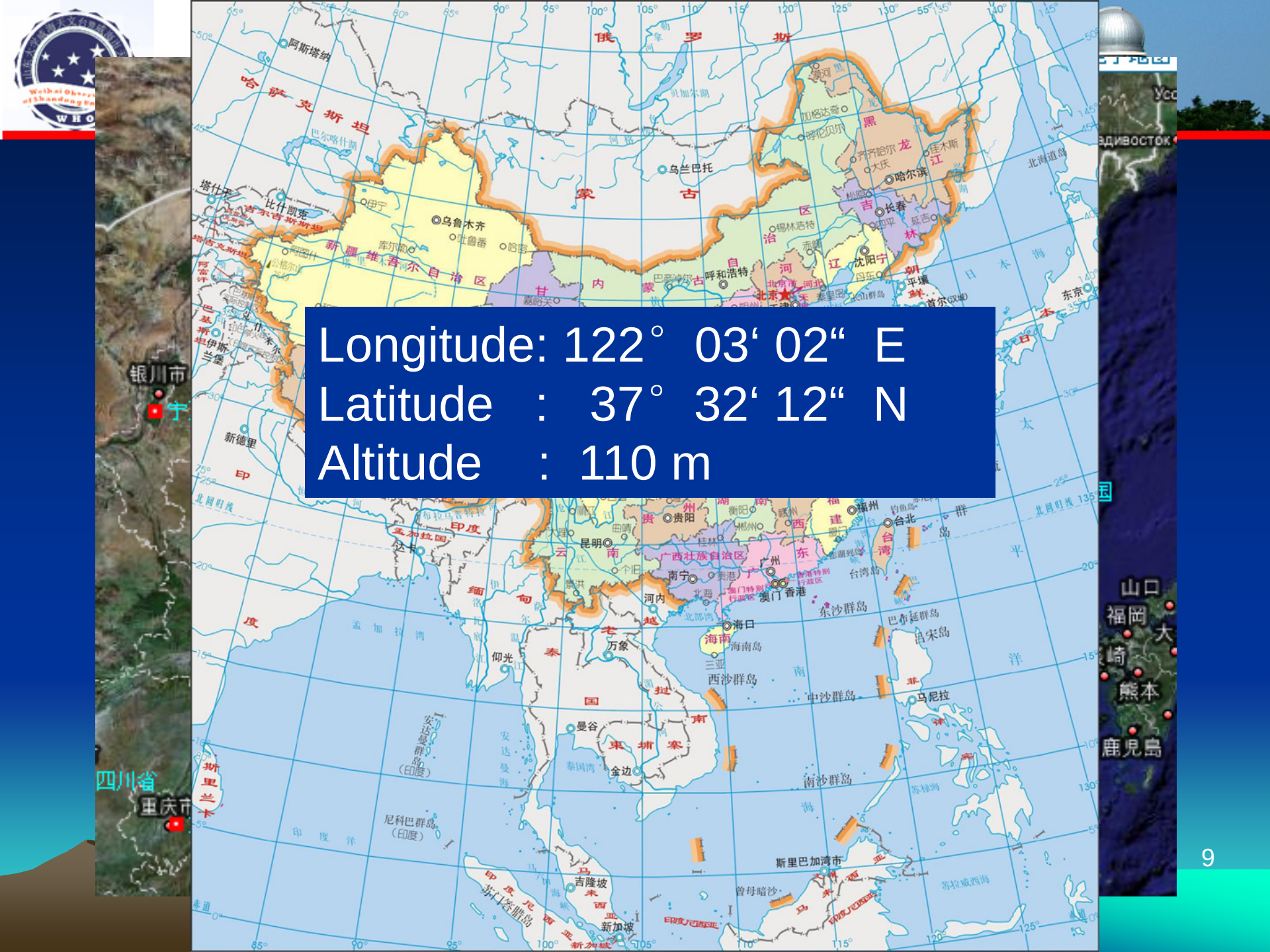
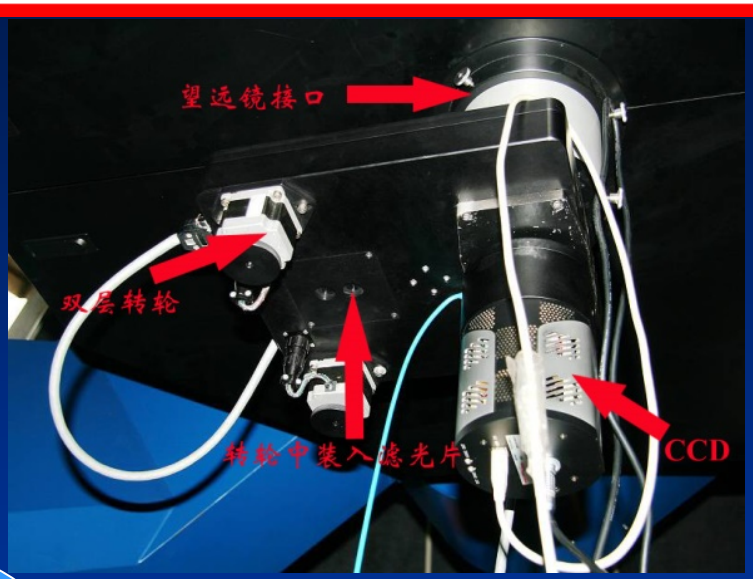
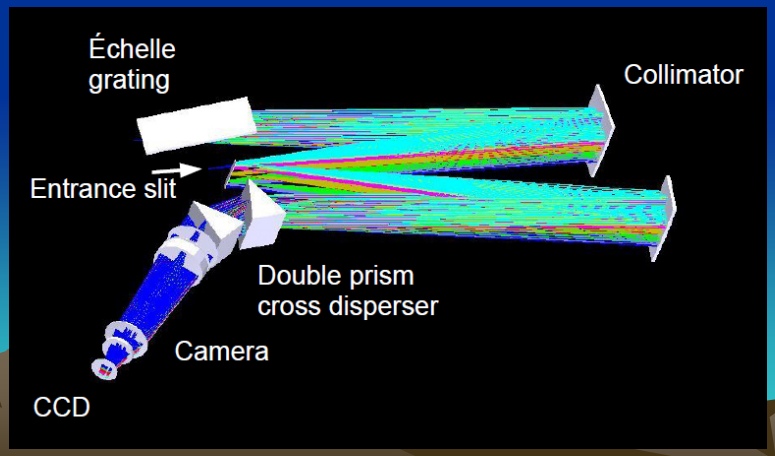
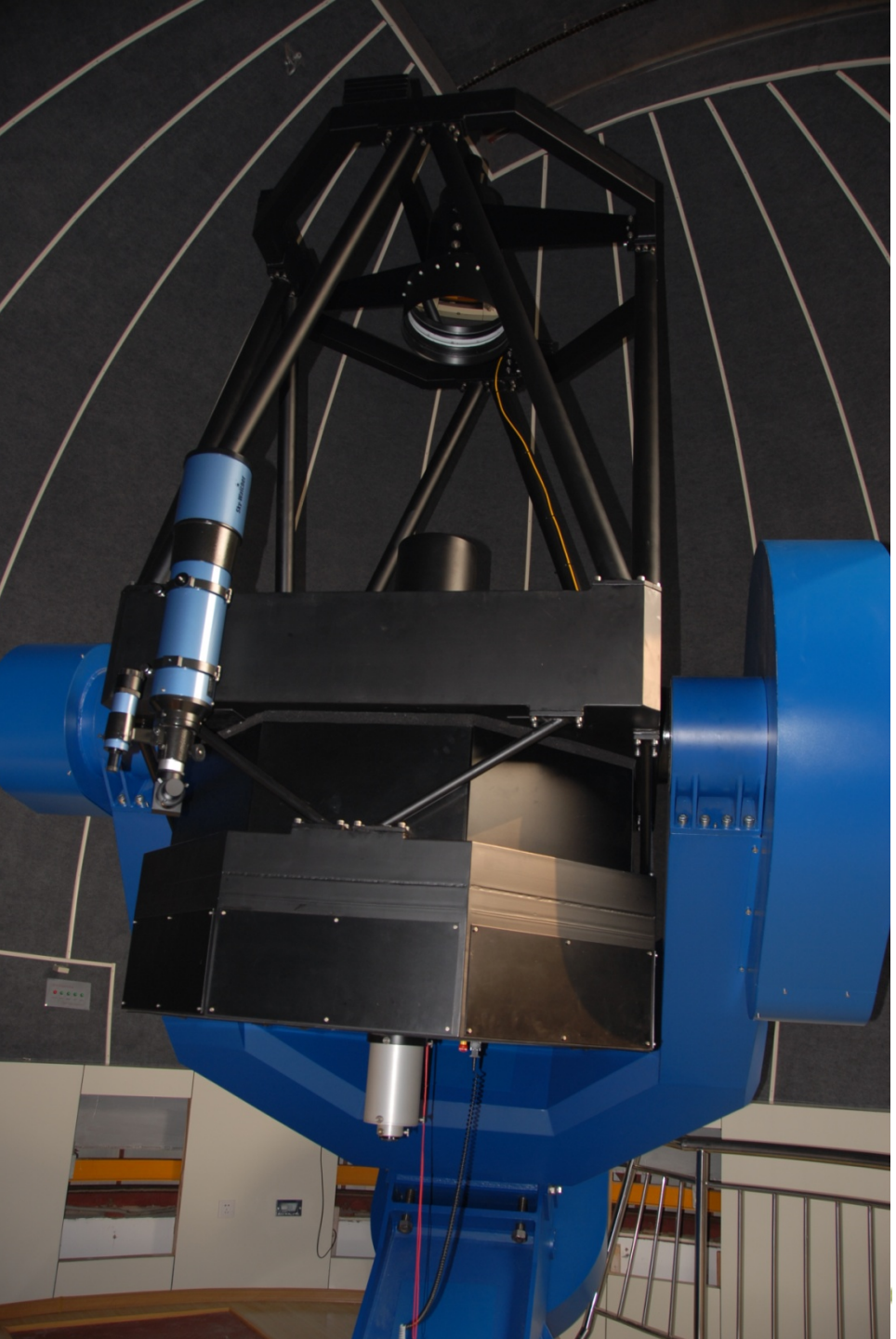

Longitude: 122° 03‘ 02“ E
Latitude : 37° 32‘ 12“ N
Altitude : 110 m

Instruments



Two Instruments





Telescope

Optics: classic Cassegrain design, 1000mm optical working diameter, focal ratio: f/8

Mount: equatorial fork mount

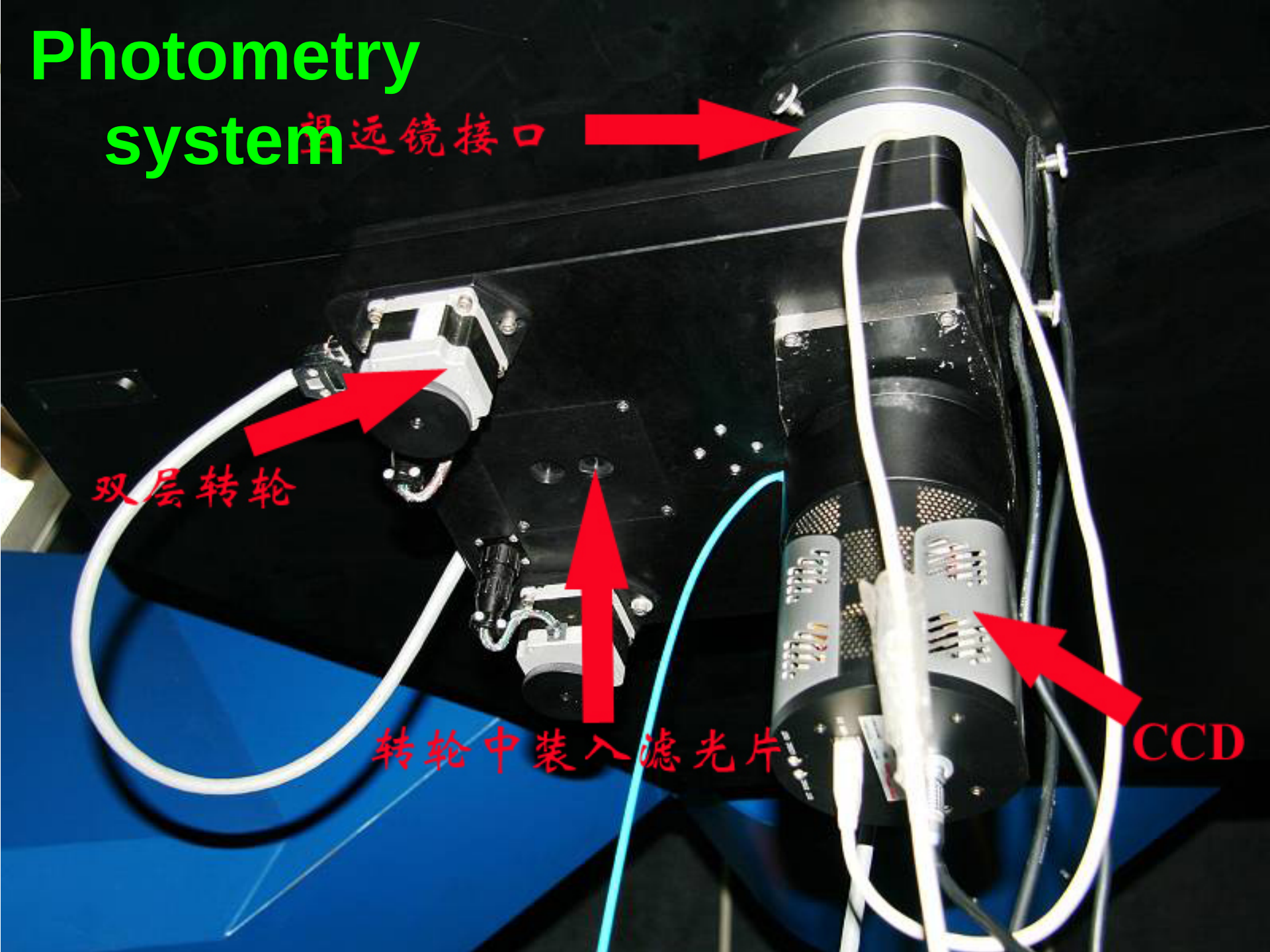
Image quality: 80% Energy in 0.65 arc sec within 15 arc minute FOV

Maximum slew speed is 4 degrees per second in both RA and DEC axis

Pointing accuracy: 5.4 arc sec RMS for 20-90 deg altitude

Tracking accuracy: 0.54 arc sec RMS in 10 minutes blind guiding

Photometry system

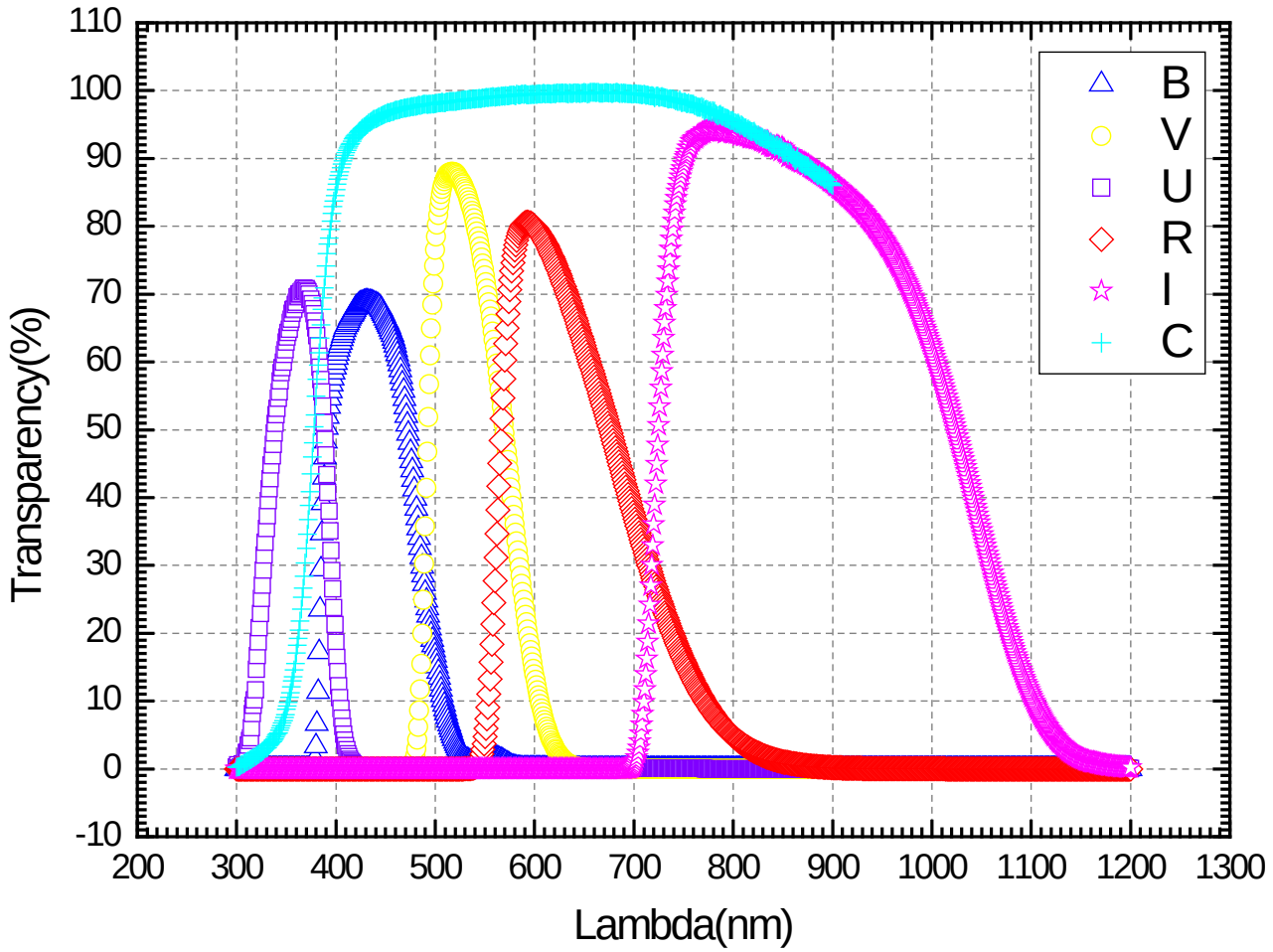


CCD Camera

PIXIS 2048B

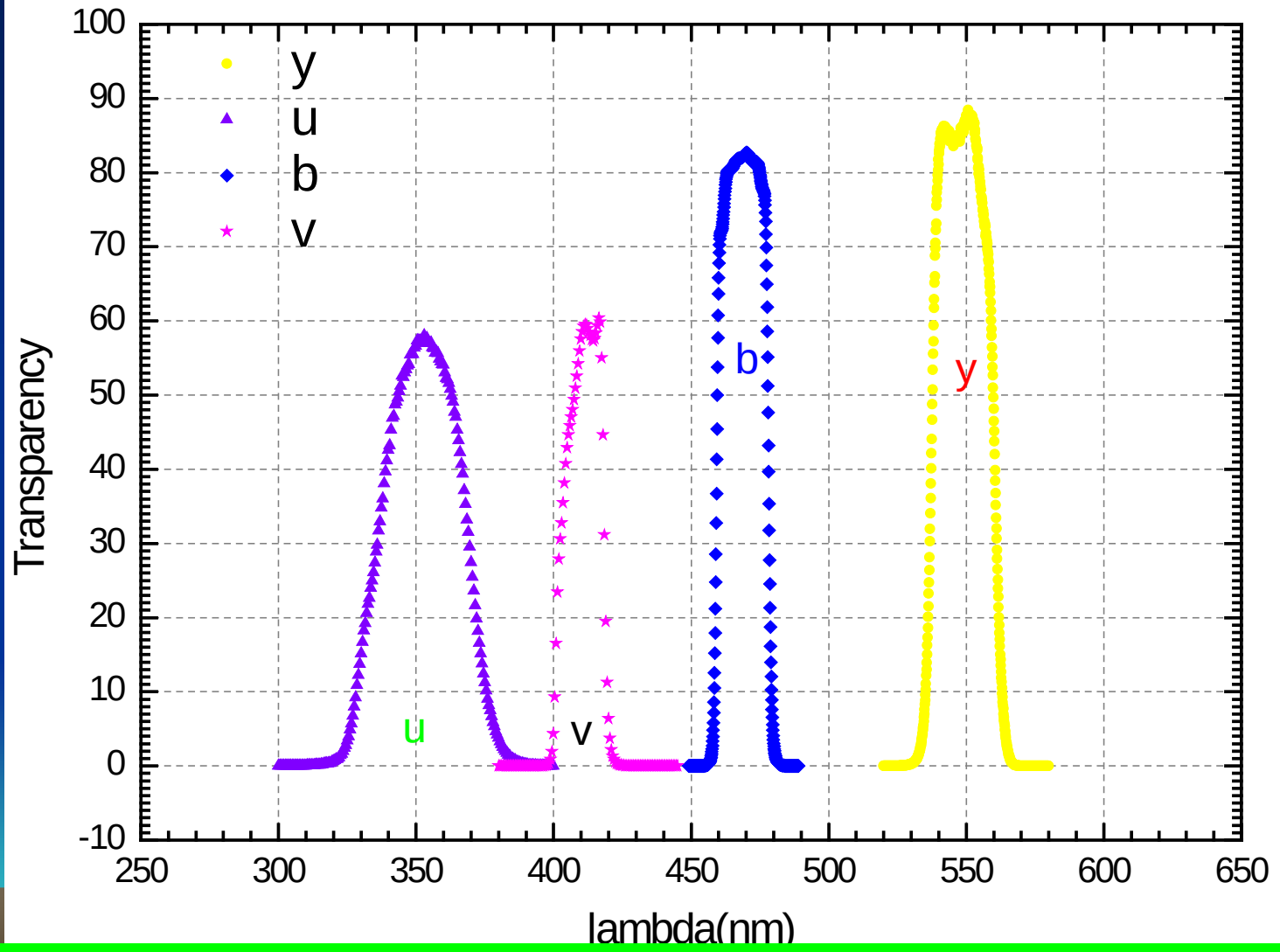
Andor **iKon-L DZ936-BV**

Filters



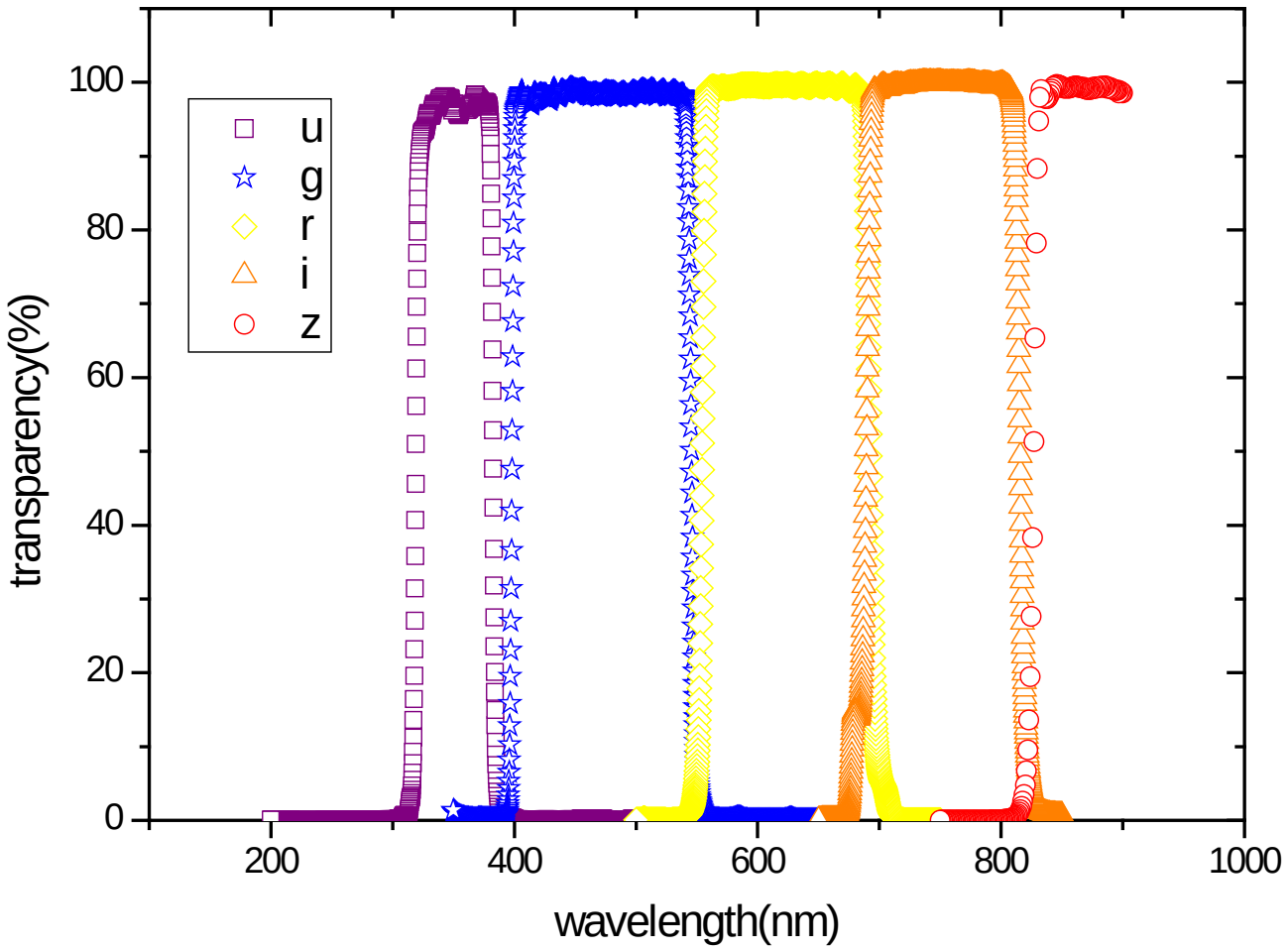
Transparency of Bessel UBVRI filters

Filters



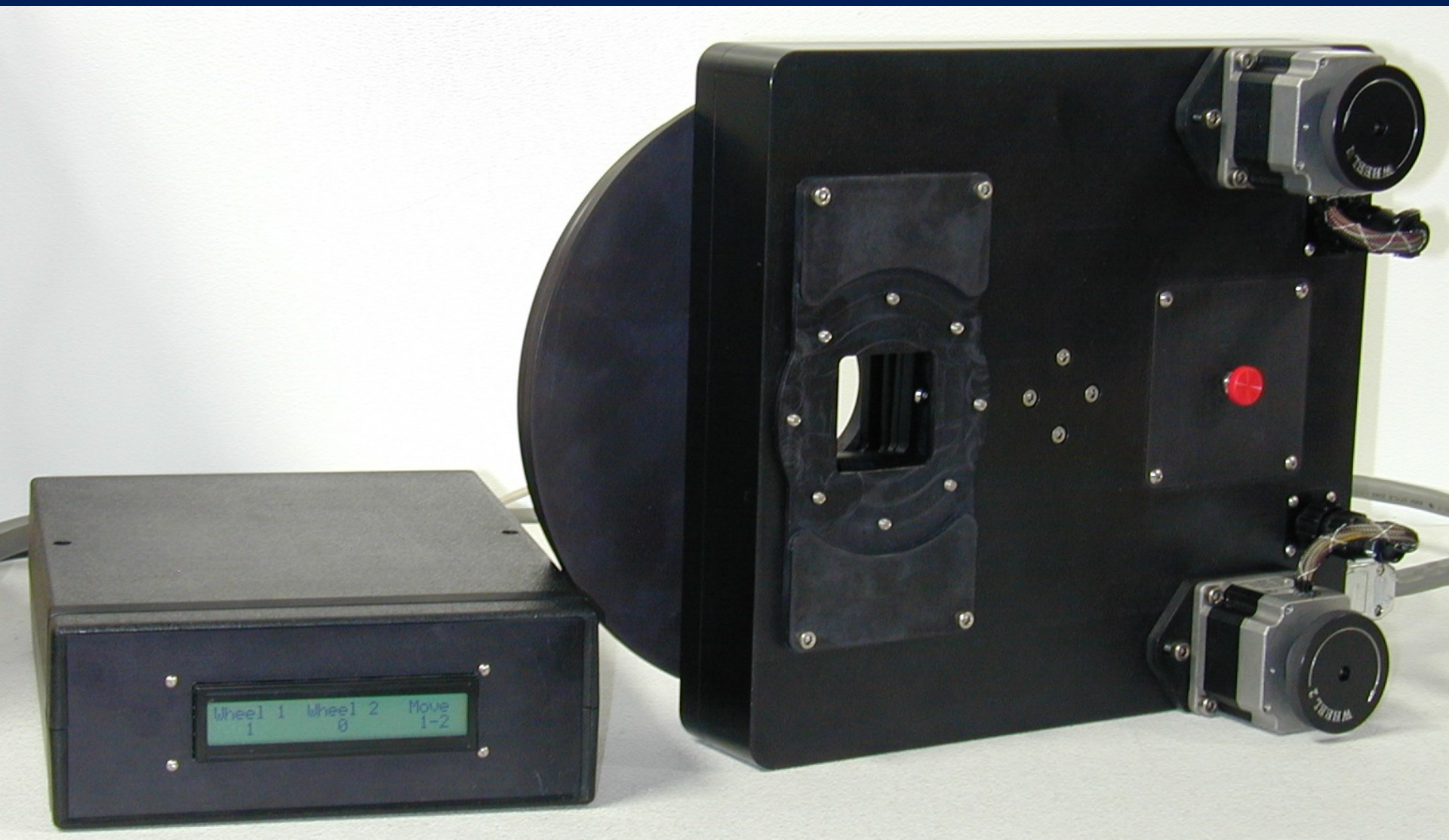
Transparency of Stromgren filters

Filters



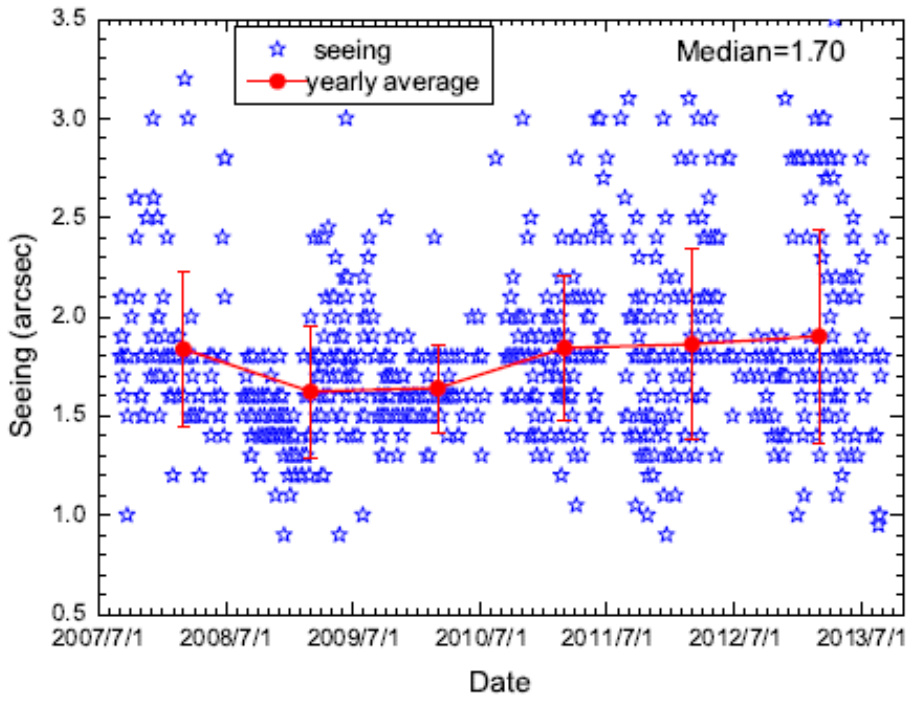
Transparency of SDSS filters

Filter wheel



ACE Dual filter wheel

Seeing



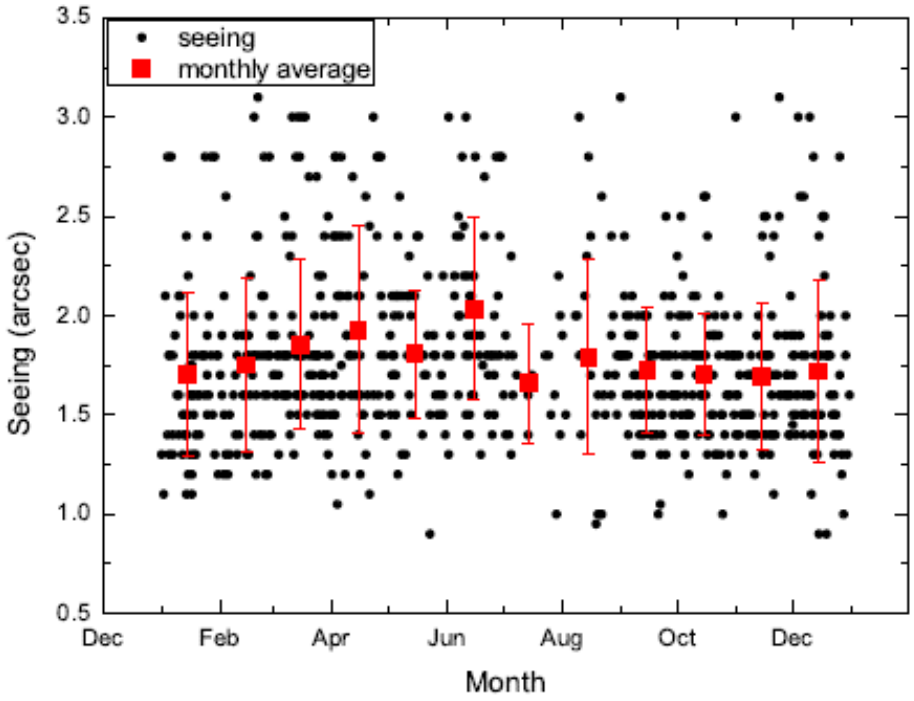
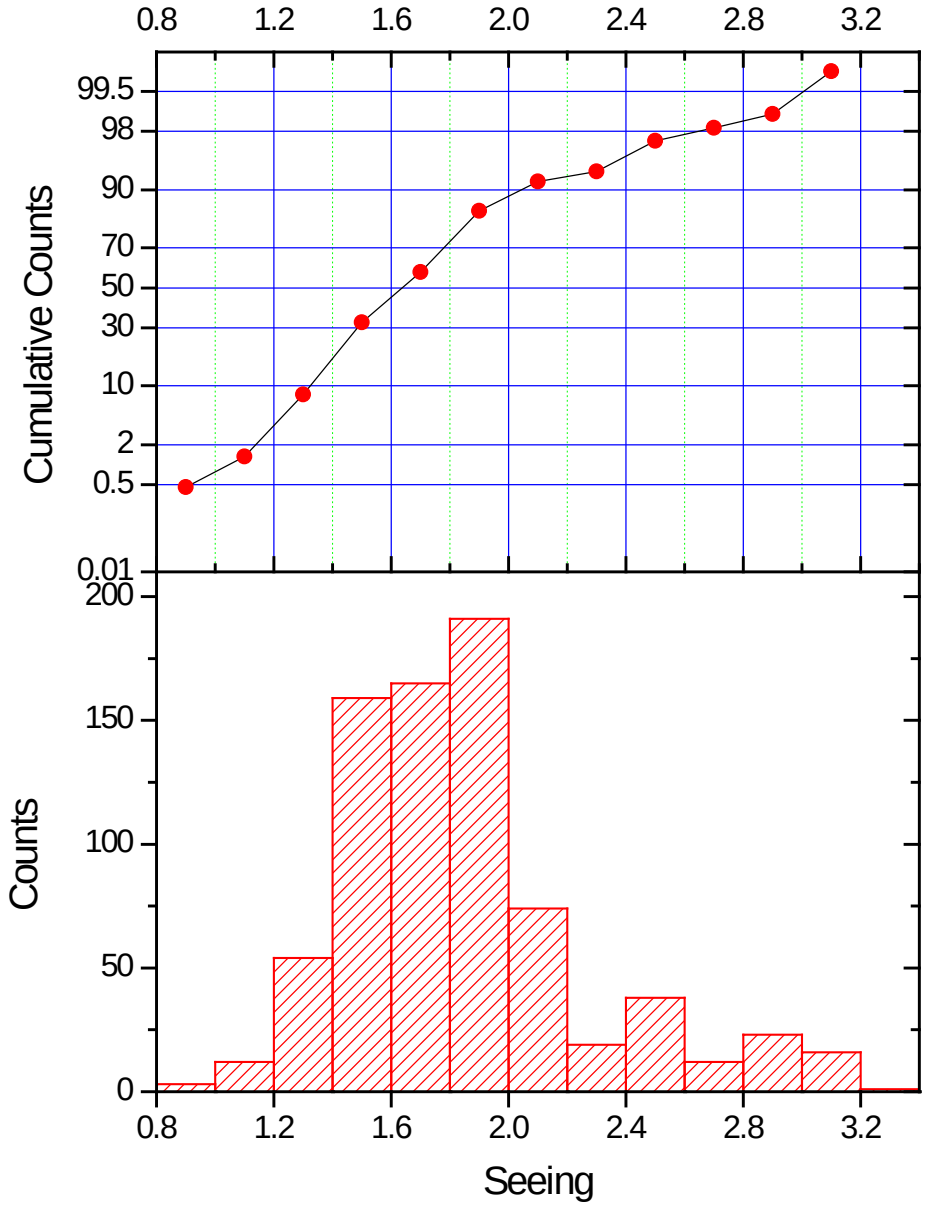


Fig. 2 *Left*: Seeing versus observation date in the past six years. Red dots describe the yearly average of the seeing. *Right*: Seasonal variation of seeing. Red solid squares illustrate the monthly average values for seeing.

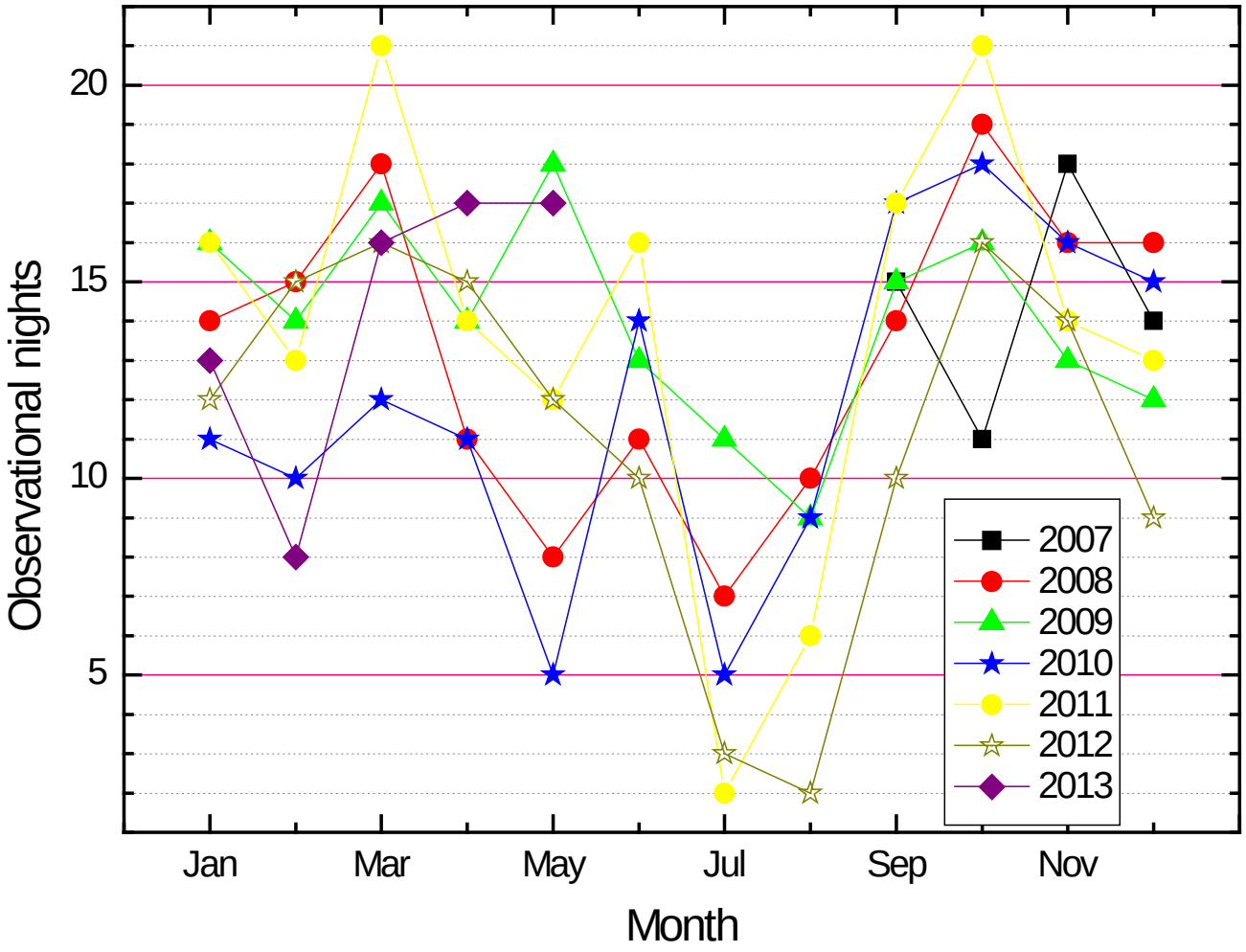
FWHM mesured by images.(768 nights, almost 6 years) see Hu et al., RAA, 16, 719, 2014.

Seeing



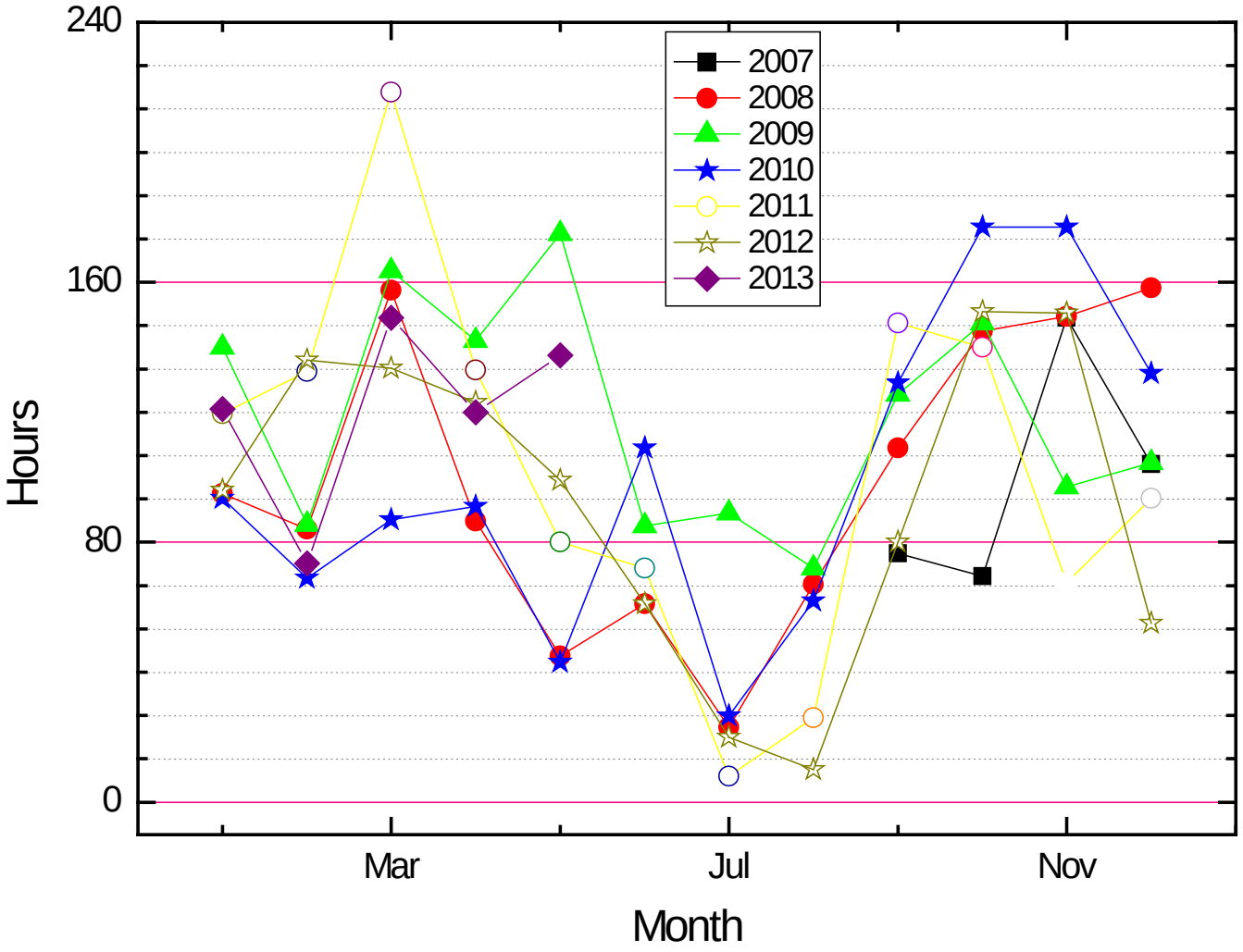
Statistic result of seeing, 90% seeing is better than 2.0 arcsecond

Weather condition



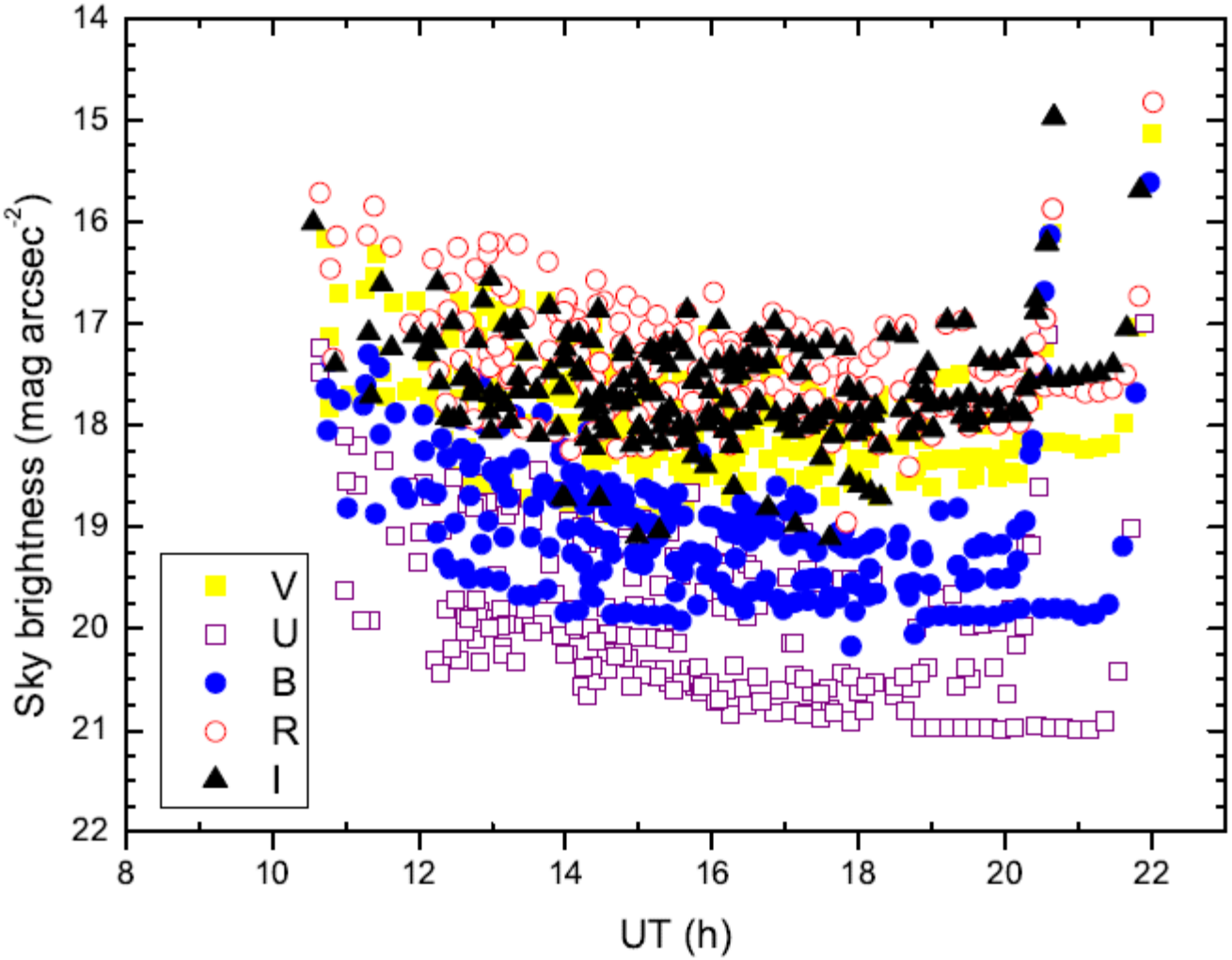
Monthly observatinal nights

Weather condition



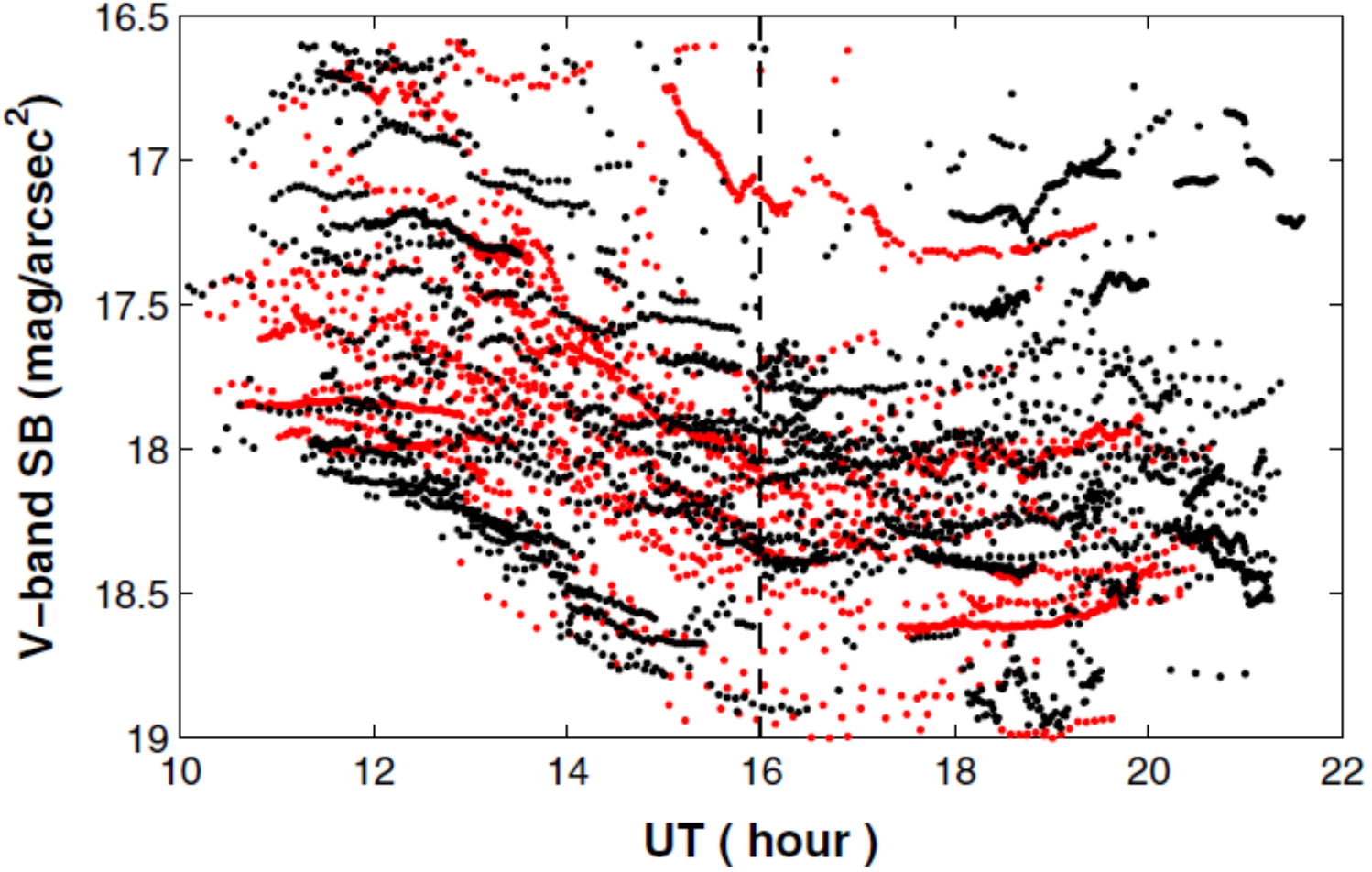
Monthly observatinal hours

Sky background



See Guo et al., PASP, 126, 496, 2014

Sky background



See Guo et al., PASP, 126, 496, 2014

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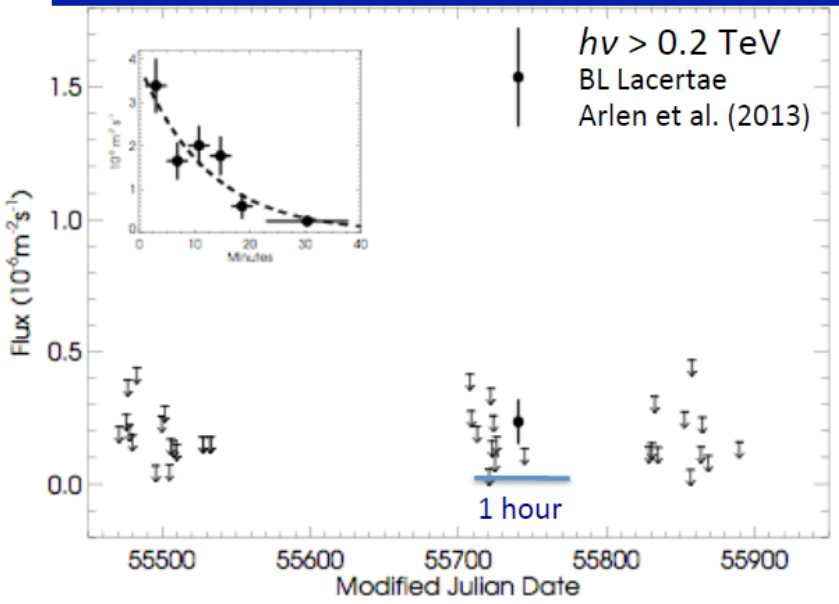
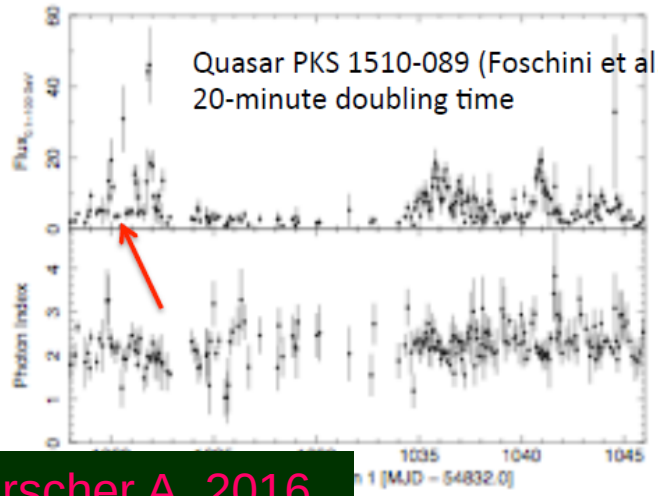
Blazar observations

Objects	Data(Bands)	Nights
0109+224		
S5 0716+714	4584(V R I)	37
BL Lac	3865(V R I)	43
OT 546	1085(V R I)	23
PKS 1424+240	4066(V R I)	42
OI 090.4	794(V R I)	21
Mrk 421	2882(V R I)	41
3C 66A	3000(V R I)	44
3C 371	380(V R I)	6
ON 231	194(V R I)	3
0954+658		
1011+496		
1246+586		
OJ 287		

Microvariability study

Problem: Intra-day Variability on Parsec Scales





Changes in flux are observed to occur on time-scales t_{var} as short as minutes

How can this occur parsecs from the black hole?

Size of region needs to smaller than ct_{var} $[\delta/(1+z)] \sim 2\times10^{14}\ t_{var,hr}\ \delta$ cm,

where z is the redshift of the host galaxy and δ is the Doppler factor (blueshift) from relativistic motion of plasma

Superluminal motion implies $\delta \sim 20 - 50$

+ Jet is very narrow (**$\sim 0.1/\Gamma_{flow}$**; Jorstad et al. 2005, Clausen-Brown et al. 2013) so jet width 1 pc from black hole $\sim 10^{17}$ cm

+ Only some fraction of jet x-section is bright at any given time

→Magnetic reconnection jet-in-jet model (Giannios 2013, MNRAS), or turbulence (Narayan & Piran 2012, MNRAS; Marscher 2012, Fermi and Jansky proc.)

Talk of Marscher A. 2016

Microvariability study

Duty cycle of microvariability for LBL:

BL Lac is 73%

0716+714 is 83.9%

OI 090.4 is 70%

Duty cycle of microvariability for HBL:

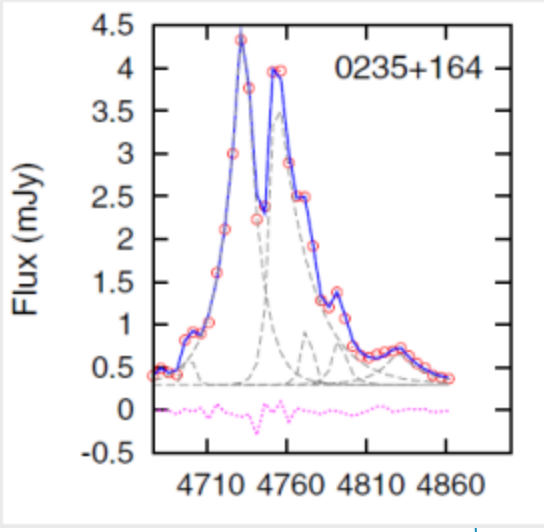
No significant IDV was found for OT 546 and Mrk 421

- Statistically the duty cycle of HBL is much lower than that of LBL. Why?
- Is it due to the stronger magnetic field of HBL to constrain the microvariability?

- Hu et al. 2006, MNRAS, 373, 209
- Hu et al., 2014, MNRAS, 443, 2940
- Hu et al., 2014, JAp&A, 35, 261
- Guo et al., 2014, JAp&A, 35, 283
- Chen et al., 2014, JAp&A, 35, 465

Statistical analysis for blazar flares

The light curves could be decomposed into individual flares using fitting methods.



2012-AJ-749:191

Valtaoja (1999)

$$\Delta S(t) = \begin{cases} \Delta S_{\max}\, e^{(t-t_{\max})/\tau}, & t < t_{\max} \\ \Delta S_{\max}\, e^{(t_{\max}-t)/1.3\tau}, & t > t_{\max} \end{cases}$$

Abdo (2010)

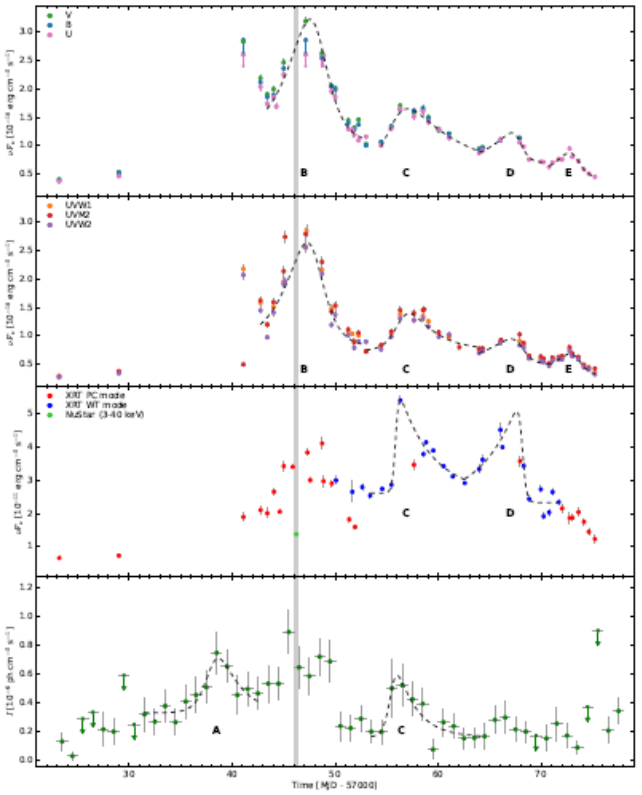
$$F(t) = F_c + F_0 \frac{1}{e^{(\frac{t_0-t}{T_r})} + e^{(\frac{t-t_0}{T_d})}}$$

Chatterjee (2012)

$$f(t) = f_0 + f_{max} \times \exp[(t-t_0)/T_r], t < t_0$$

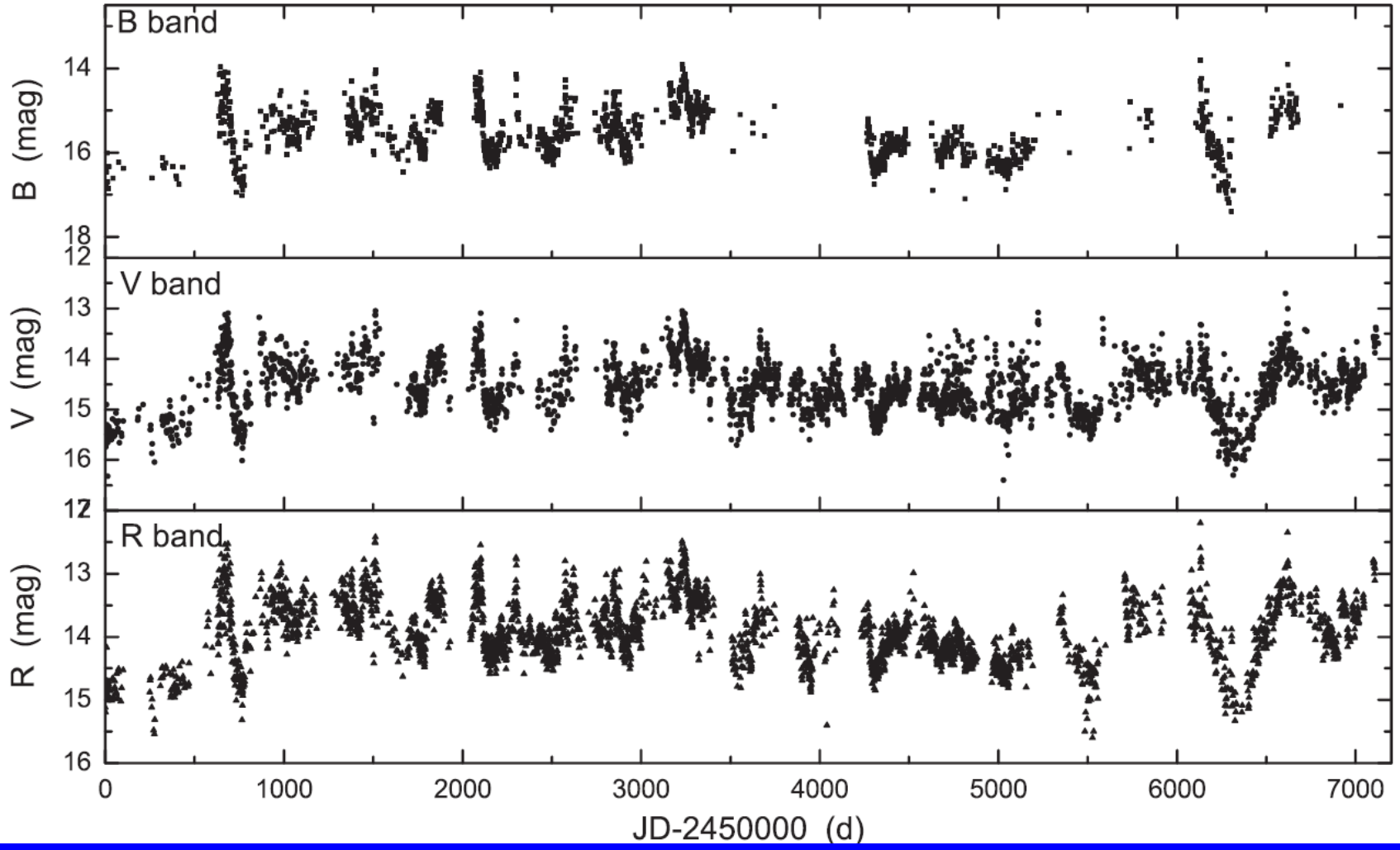
$$= f_0 + f_{max} \times \exp[-(t-t_0)/T_d], t > t_0$$

Wierzcholska(2016)



Results for BL Lac

Optical light curves of BL Lacertae in B, V and R bands



See Guo, Hu et al. 2016,MNRAS, 460, 1790

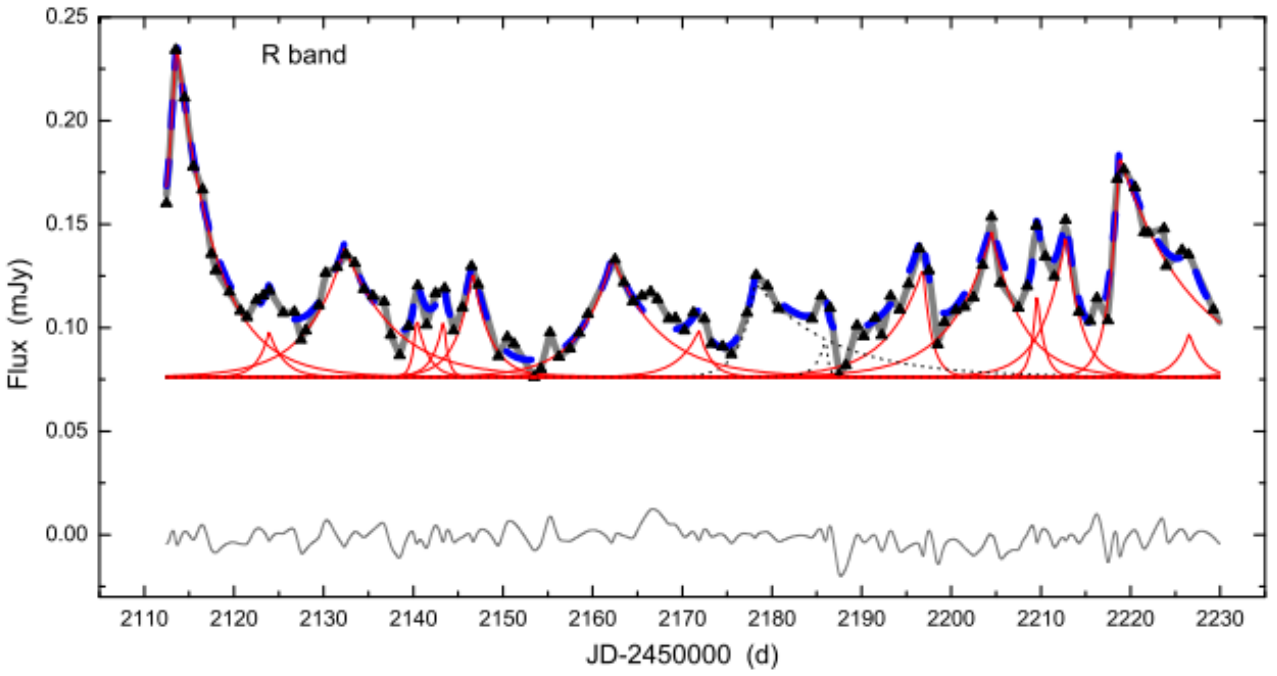
Flare fitting

- We adopted an exponential function introduced by Valtaoja et al. (1999) to decompose the flares.

$$f(t) = \begin{cases} f_0 + f_{max} exp\left[(t - t_0)/T_r\right], \ for\ t < t_0\ and \\ f_0 + f_{max} exp\left[-(t - t_0)/T_d\right], \ for\ t > t_0 \end{cases}$$

- Before the fitting of flares, all segments were interpolated linearly by a time interval τ_{in}, then smoothed by a Gaussian function with particular FWHM

In order to optimize the fitting of flares and obtain the best result, different segment was applied to different τ_{in} and FWHM.



Properties of Flares

- Flare duration time

$$T \simeq 2(T_r + T_d)$$

- Skewness parameter

$$\xi = \frac{T_d - T_r}{T_d + T_r}$$

- Amplitude of flare

$$f_{max}$$

- Energy output

$$Area = \int_{-\infty}^{+\infty} f(t) - f_0 \, dt = f_{max}(t_r + t_d)$$

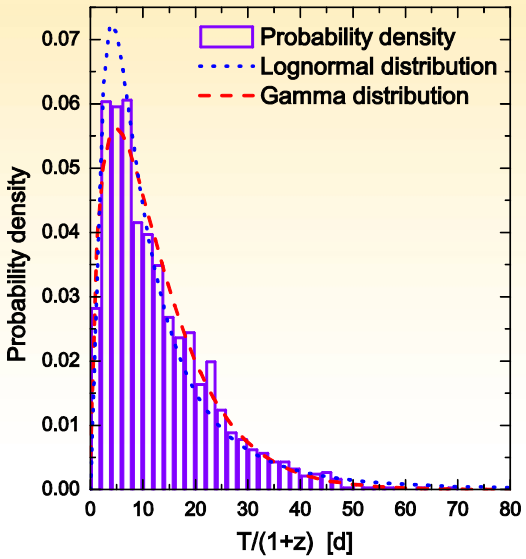
Flare duration

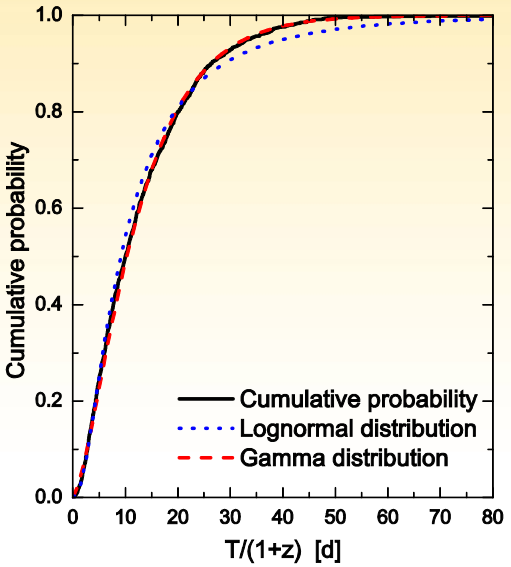
- The probability density and cumulative probability of T/(1+z) are shown. Gamma distribution seemed to be appropriate to explain this distribution according to K-S test.
- lognormal distribution

$$f(x|\mu,\sigma) = \frac{1}{\sqrt{2\pi}\sigma x} e^{\frac{-(lnx-\mu)^2}{2\sigma^2}}$$

- gamma distribution

$$f(x|a,b) = \frac{1}{b^a \Gamma(a)} x^{a-1} e^{-\frac{x}{b}}$$





	band	Lognormal distribution			Gamma distribution		
		μ	σ	h	a	b	h
$T/(1+z)$	all	2.212±0.021	0.897±0.015	1	1.610±0.048	7.978±0.280	0
f_{max}	V	-2.774±0.024	0.710±0.017	0	2.178±0.099	0.037±0.002	1
	R	-2.597±0.029	0.773±0.021	0	1.797±0.089	0.056±0.003	1
$Area$	V	-1.214±0.045	1.319±0.032	0	0.764±0.032	0.849±0.049	1
	R	-0.967±0.048	1.254±0.034	0	0.840±0.039	0.913±0.057	1

VARIABILITY ANALYSIS RESULTS ——Flare asymmetry

- Distributions of ξ are presented in the plot. The red line in each panel presents the result of Gaussian fitting. Mean and standard deviation of the Gaussian function (μ and σ, respectively) are listed in table 1.
- Despite different τ_{in} and FWHM shown in table 1, μ were slightly less than zero within the statistical uncertainties, reflecting that **there might be a trend toward gradual rises and rapid decays. Or we could safely say that no or at most very weak negative asymmetry were found in the variations of BL Lacertae.**

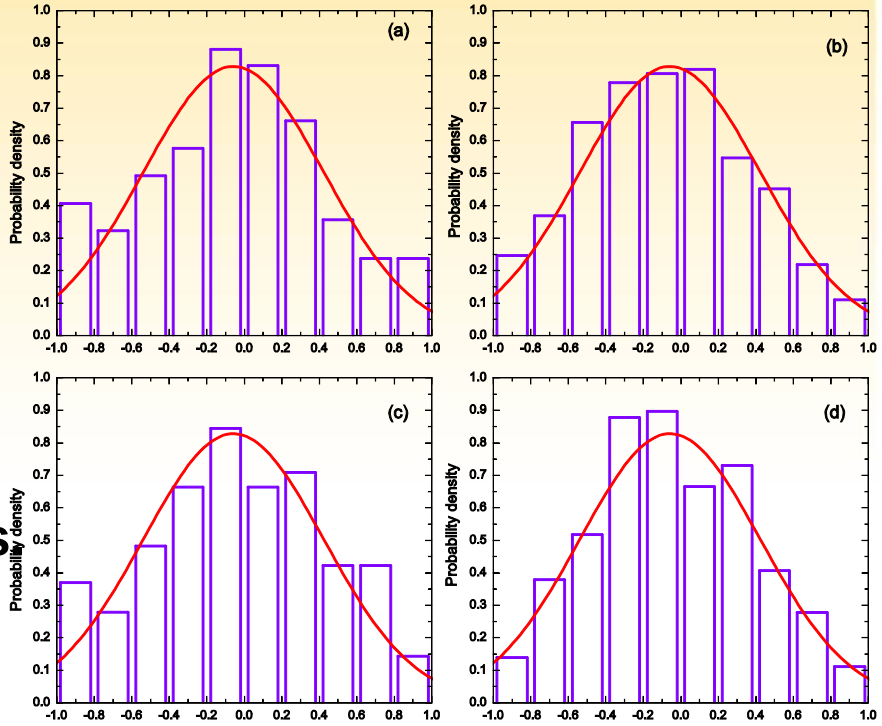
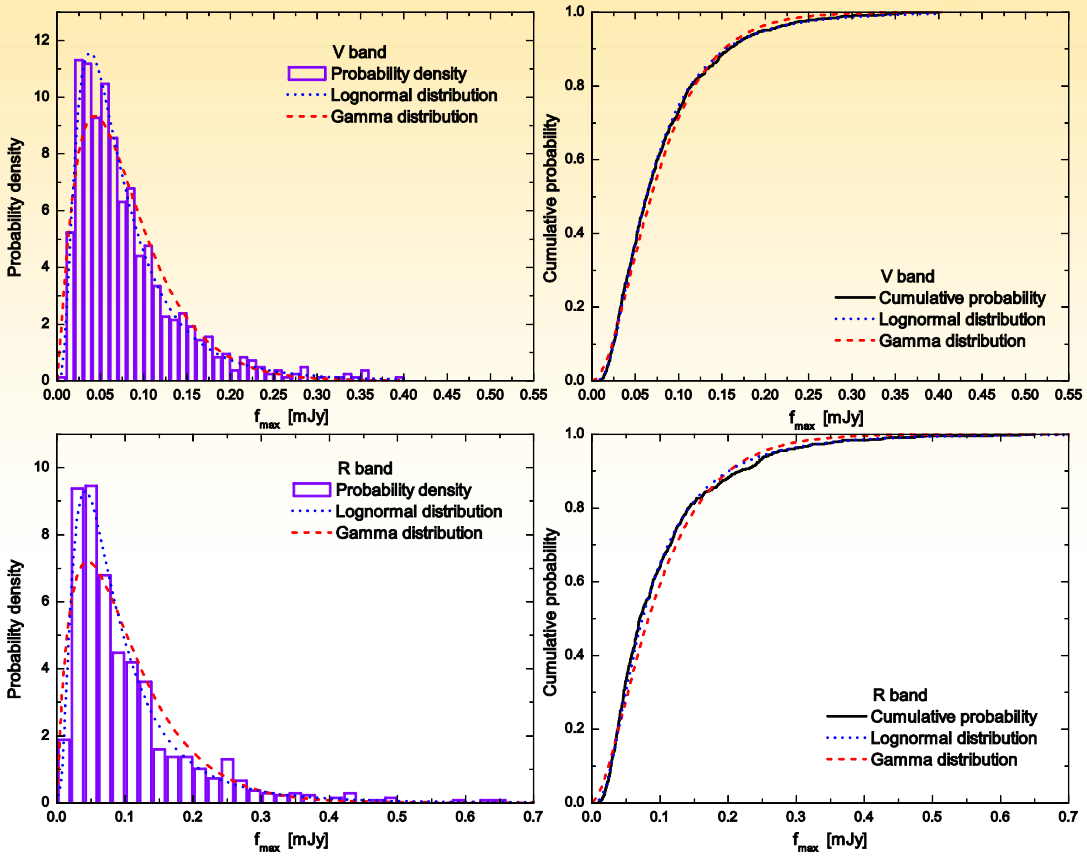


Table 1. Statistics of flares.

type	linear interpolation	gauss smoothing	number of flares				Gaussian Fitting		$-0.3 < \xi < 0.3$	$0.3 < \lvert\xi\rvert < 0.7$	$0.7 < \lvert\xi\rvert < 1$
	τ_{in}	$FWHM$	B band	V band	R band	sum	μ	σ			
a	$0.5 \sim 1$	1	20	195	80	295	-0.058±0.028	0.482±0.020	47.5%	33.2%	19.3%
b	$0.5 \sim 1$	5	37	214	115	366	-0.080±0.023	0.437±0.016	47.3%	40.7%	12.0%
c	$0.1 \sim 0.5$	1	147	273	243	663	-0.030±0.019	0.479±0.013	44.6%	38.5%	16.9%
d	$0.1 \sim 0.5$	5	120	166	255	541	-0.047±0.018	0.421±0.013	50.3%	39.2%	10.5%

Peak flux of flares

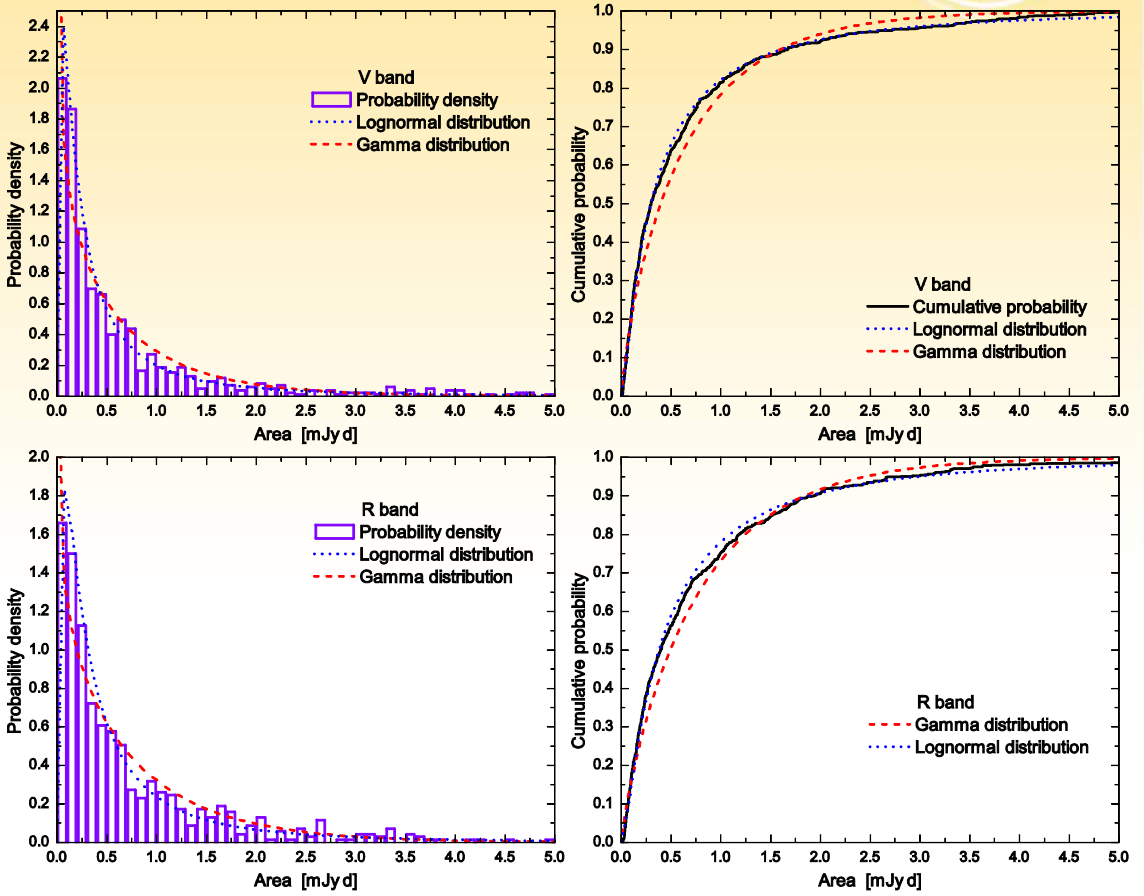
- The probability density and cumulative probability of f_{max} of the flares in V bands and R bands are depicted in the plots. Lognormal distribution seemed to be more precise to explain the distribution of fmax.



	band	Lognormal distribution			Gamma distribution		
		μ	σ	h	a	b	h
$T/(1+z)$	all	2.212±0.021	0.897±0.015	1	1.610±0.048	7.978±0.280	0
f_{max}	V	-2.774±0.024	0.710±0.017	0	2.178±0.099	0.037±0.002	1
	R	-2.597±0.029	0.773±0.021	0	1.797±0.089	0.056±0.003	1
$Area$	V	-1.214±0.045	1.319±0.032	0	0.764±0.032	0.849±0.049	1
	R	-0.967±0.048	1.254±0.034	0	0.840±0.039	0.913±0.057	1

Energy output of fares

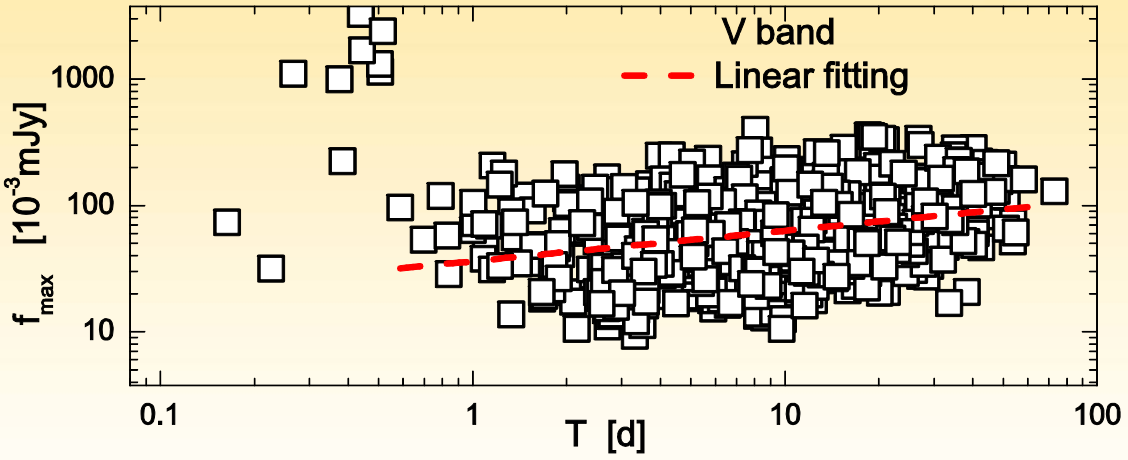
- The probability density and cumulative probability of Area in V bands and R bands are depicted. Lognormal distribution seemed to be more precise to explain the distribution of fmax.

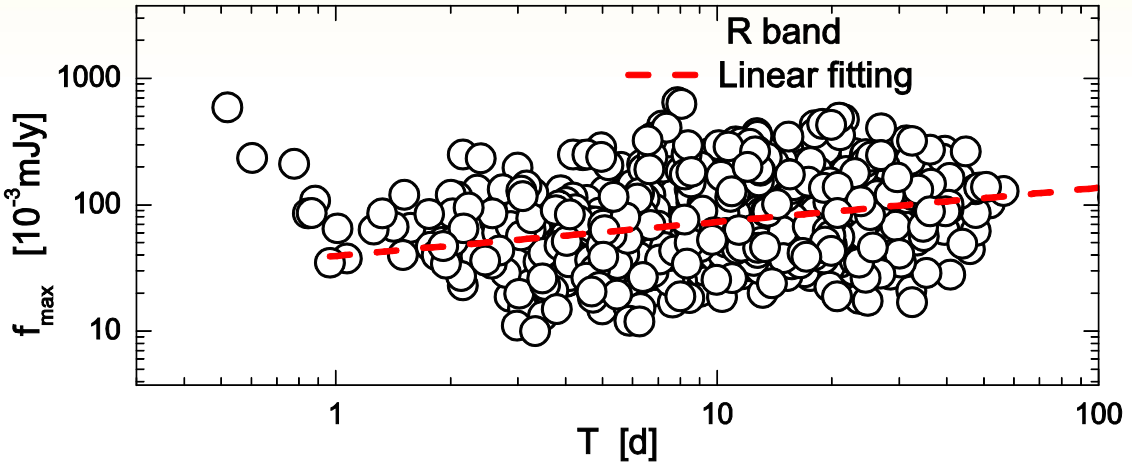


	band	Lognormal distribution			Gamma distribution		
		μ	σ	h	a	b	h
$T/(1+z)$	all	2.212±0.021	0.897±0.015	1	1.610±0.048	7.978±0.280	0
f_{max}	V	-2.774±0.024	0.710±0.017	0	2.178±0.099	0.037±0.002	1
	R	-2.597±0.029	0.773±0.021	0	1.797±0.089	0.056±0.003	1
$Area$	V	-1.214±0.045	1.319±0.032	0	0.764±0.032	0.849±0.049	1
	R	-0.967±0.048	1.254±0.034	0	0.840±0.039	0.913±0.057	1

Correlation between T and fmax

- Despite the divergency, there is a clear correlation that fmax becomes larger with a larger T.

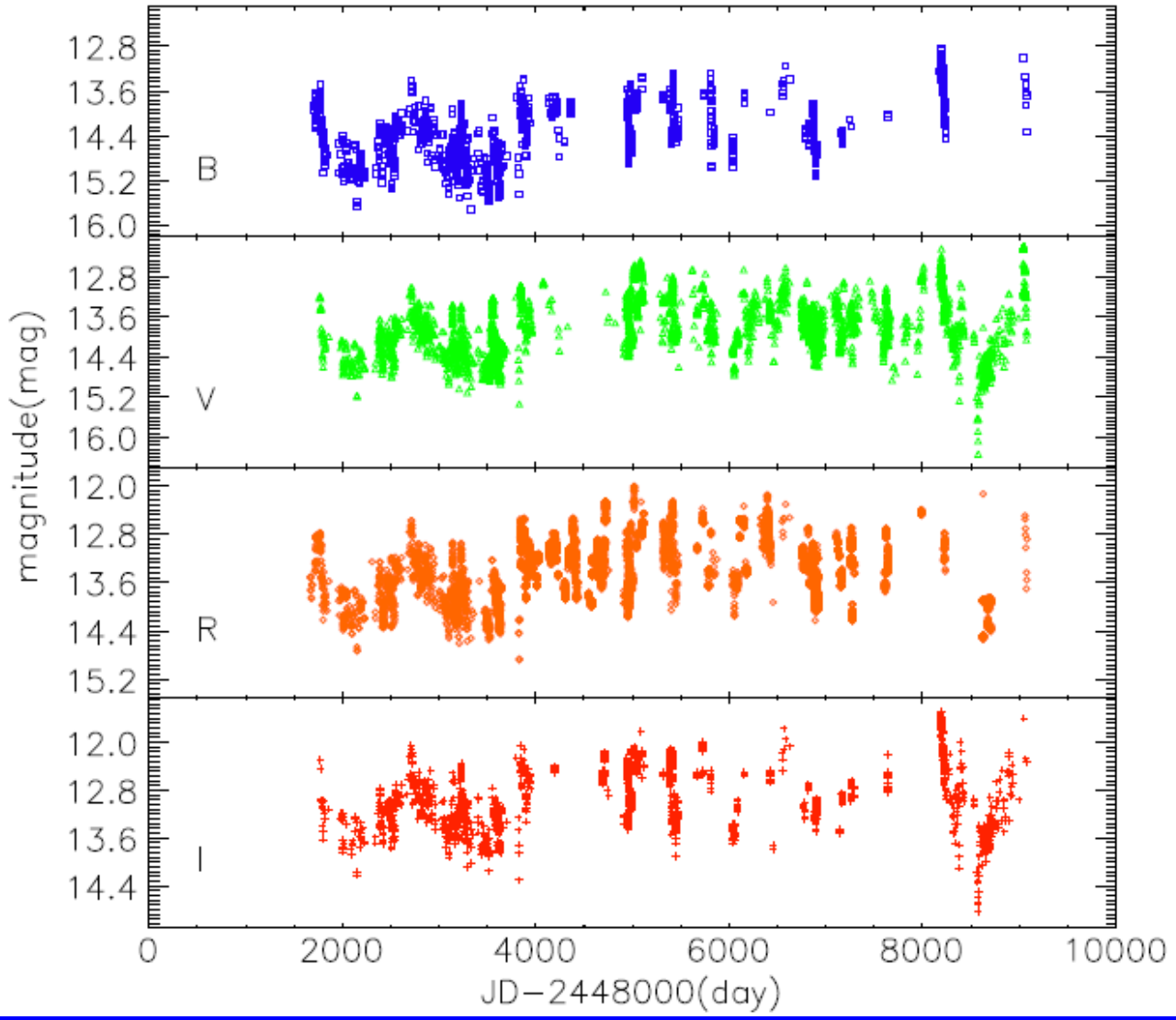




$$log(f^{V}_{max}) \propto (0.241 \pm 0.026) log(T)$$

$$log(f^{R}_{max}) \propto (0.269 \pm 0.035) log(T)$$

Results for 0716



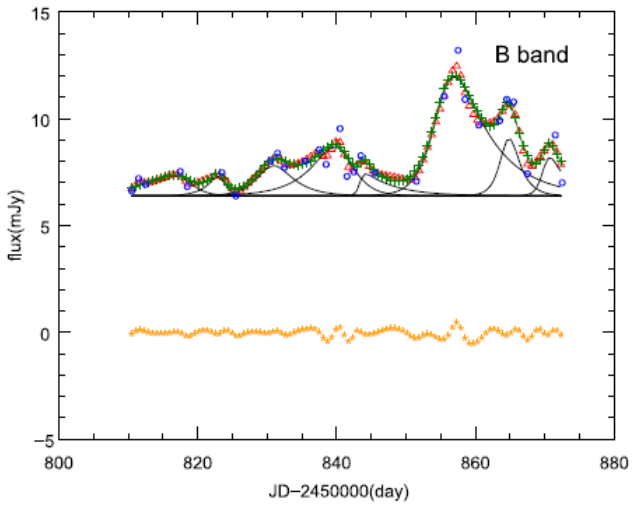
See Li, Hu et al. 2017, PASP, 129, 4101

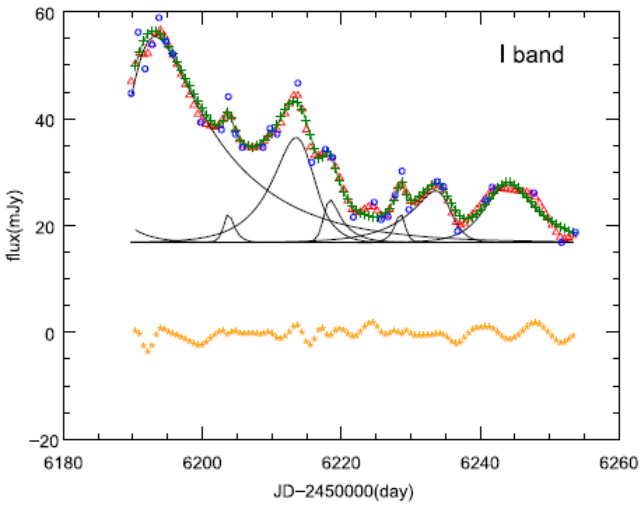
Temporal Structure of S5 0716+714

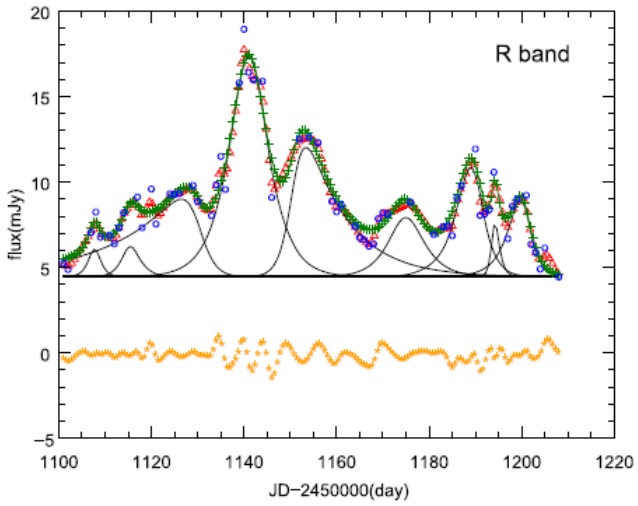
➢ Flares of Short-term Light Curves

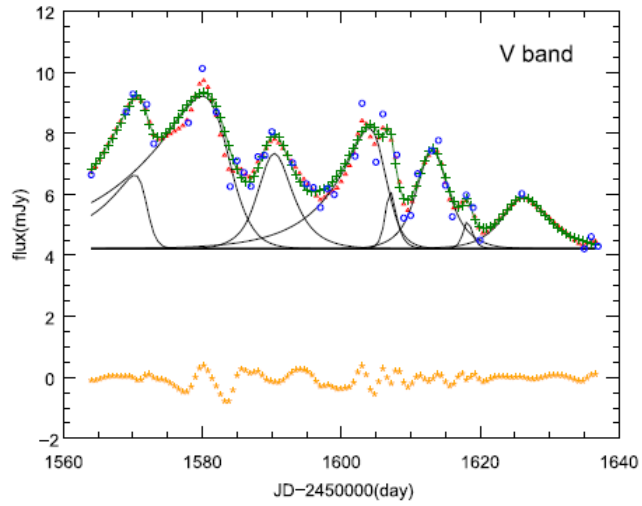
$$f(t) = f_0 + f_{max} \times \exp[(t - t_0)/T_r], t < t_0$$

$$= f_0 + f_{max} \times \exp[-(t - t_0)/T_d], t > t_0$$

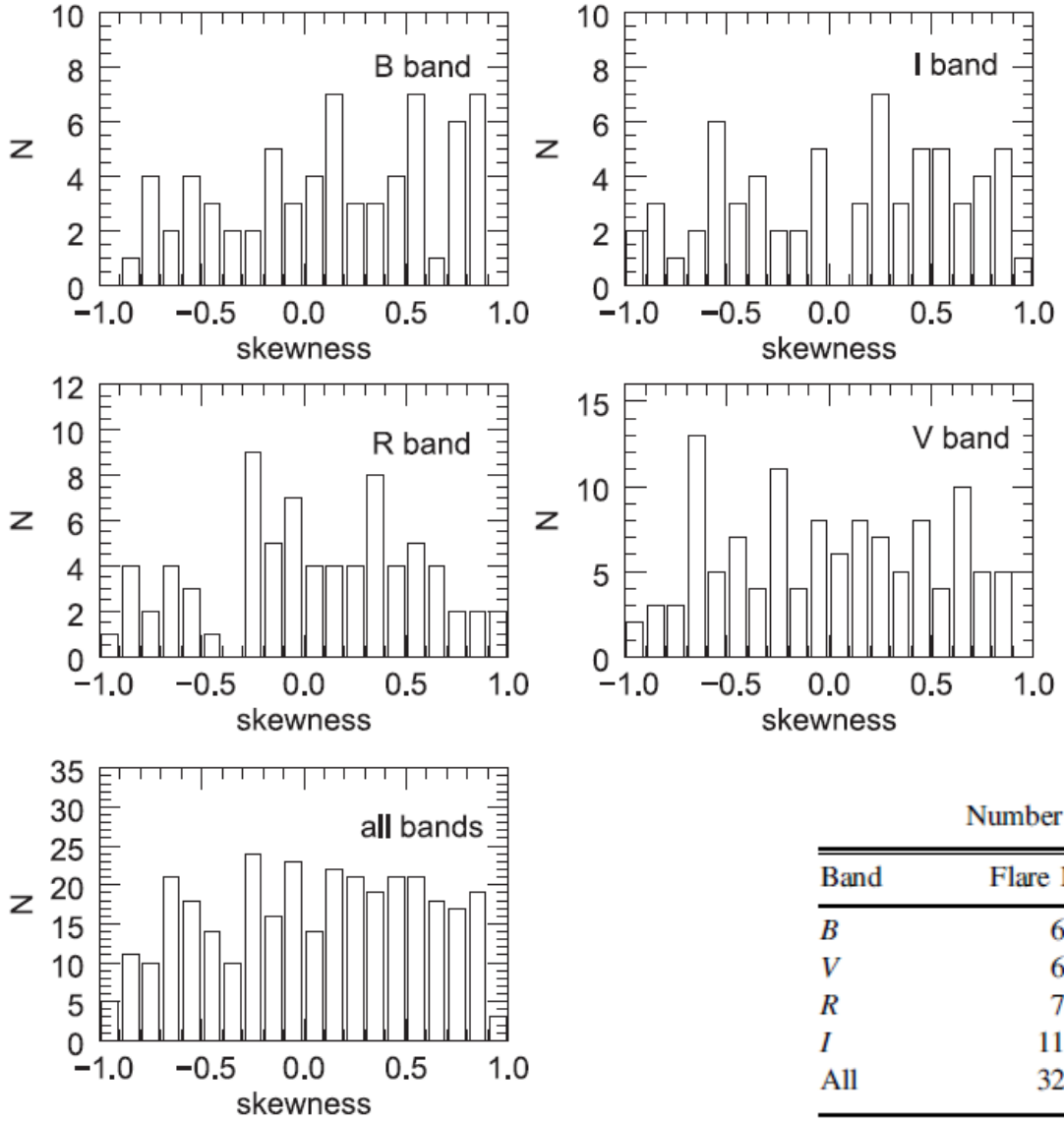








Sknewness-STV

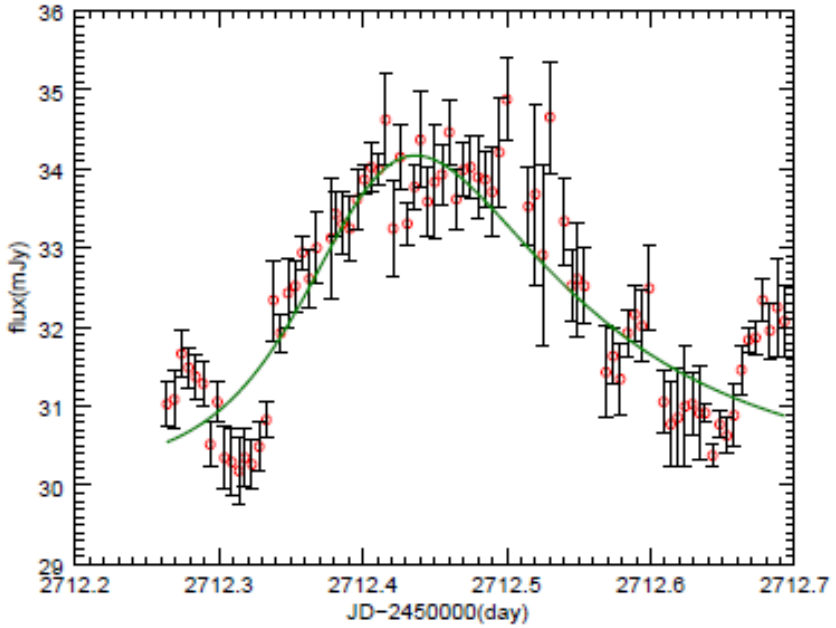


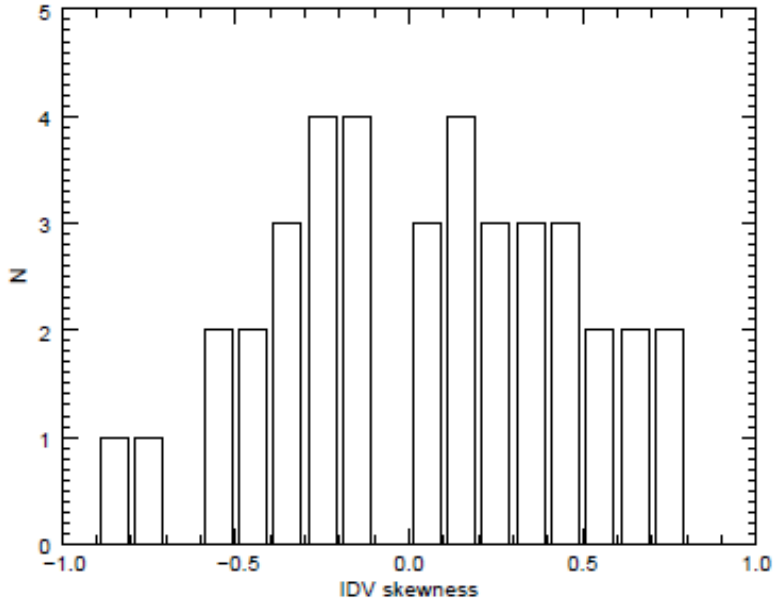
The results show that the flares are predominantly asymmetric in four bands. there exists a very weak tendency of positive asymmetry with rapid rises and gradual decays.

Table 1
Number of Flares and Percentage of $|\xi|$ in Each Band

Band	Flare Num.	<0.3	0.3 ~ 0.7	0.7 ~ 1.0
B	68	35.3%	38.2%	26.5%
V	66	28.8%	47.0%	24.2%
R	75	44.0%	38.7%	17.3%
I	118	37.3%	47.5%	15.2%
All	327	36.7%	43.4%	19.9%

Sknewness-IDV



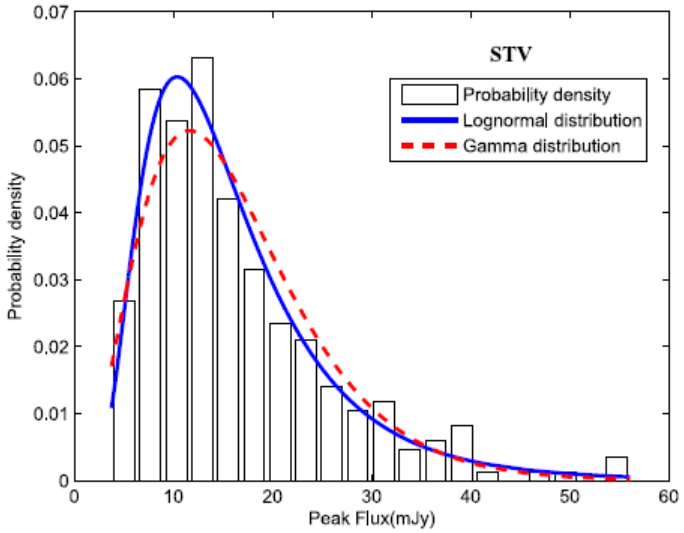


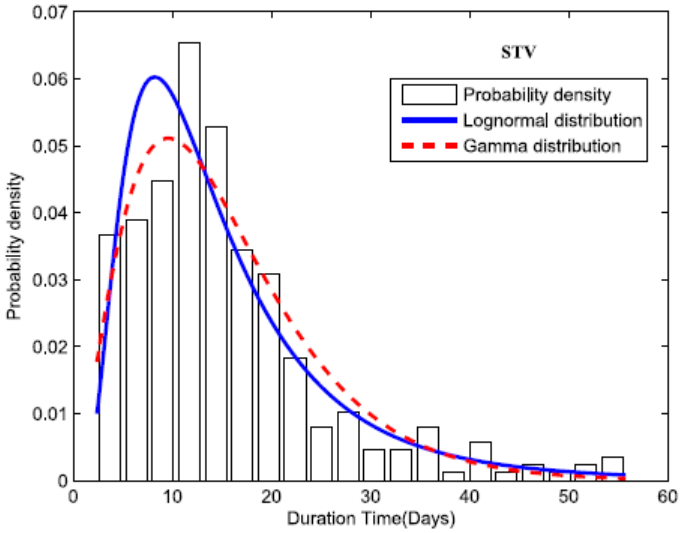
Band	skewness percentage$\lvert\xi\rvert$		
	< 0.3	$0.3 \sim 0.7$	$0.7 \sim 1.0$
All	46.2%	43.6%	10.2%

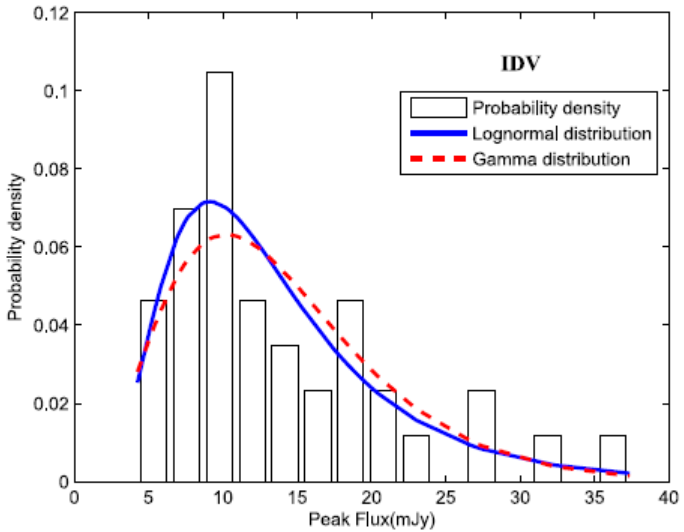
Both STV and IDV flares were predominantly asymmetric. But the percentage of symmetric flares for IDV is higher than STV.

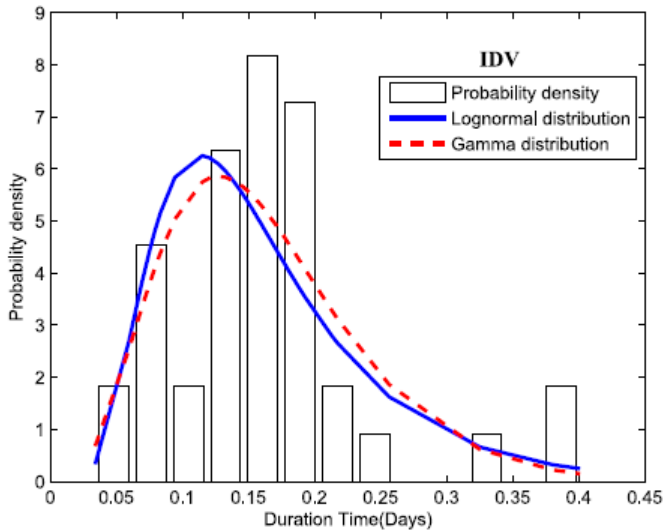
$$f_p = f_0 + f_{max}$$

$$T \simeq 2(T_r + T_d)$$









the Fig.1 of Biteau et al. (2012). For a large number of minijets, typically $N \geq 10^3$, the distribution of the logarithm of the flux can be described with a peak, followed by a power-law tail, which could be interpreted very well as a log-normal distribution. The statistics of S5 0716+714 in peak

- The Log-normal distribution of the flux suggests that the variability seems from multiplicative processes.
- Maybe a minijets-in-a-jet statistical model

(Biteau et al. 2012)

- The Gamma distribution could demonstrate that the emission region in the jet may be distributed in a Poisson way.

(Touati et al. 2009)

Discussions

A power law function, continuously injected for $t_{inj} \sim R/c$.

$\tau_{\rm cool} \ll {}^{R}/_{c}$ symmetric light curves

$\tau_{\rm cool} \gg {}^{R}/_{c}$ asymmetric light curves

For symmetric light curves:

$t < {}^{R}/_{c}$ flux increase
$t > {}^{R}/_{c}$ flux decrease

MNRAS,1999,306,551

Discussions

$$\tau_{syn} = \frac{3m_e c}{4\sigma_T U_B \gamma}$$

$$U_B = \frac{B^2}{8\pi}$$

$$\tau_{cool} = \frac{7.7 \times 10^8}{\gamma B^2} s$$

Chen et al. ,MNRAS, 2011,416, 2368

For blazar S5 0716+714, Ghisellini et al. (1997) derived the magnetic field and gamma in homogeneous synchrotron self Compton model with B = 0.48 (or B = 0.84) Gauss, and $\gamma_{min} = 3 \times 10^3, \gamma_{max} = 10^5$. Therefore, with the Equation 6, we can calculate the cooling time range is $3.3 \times 10^4 \sim 1.1 \times 10^6 s$ (B = 0.48) or $1.1 \times 10^4 \sim 3.6 \times 10^5 s$ (B = 0.84).

Discussions

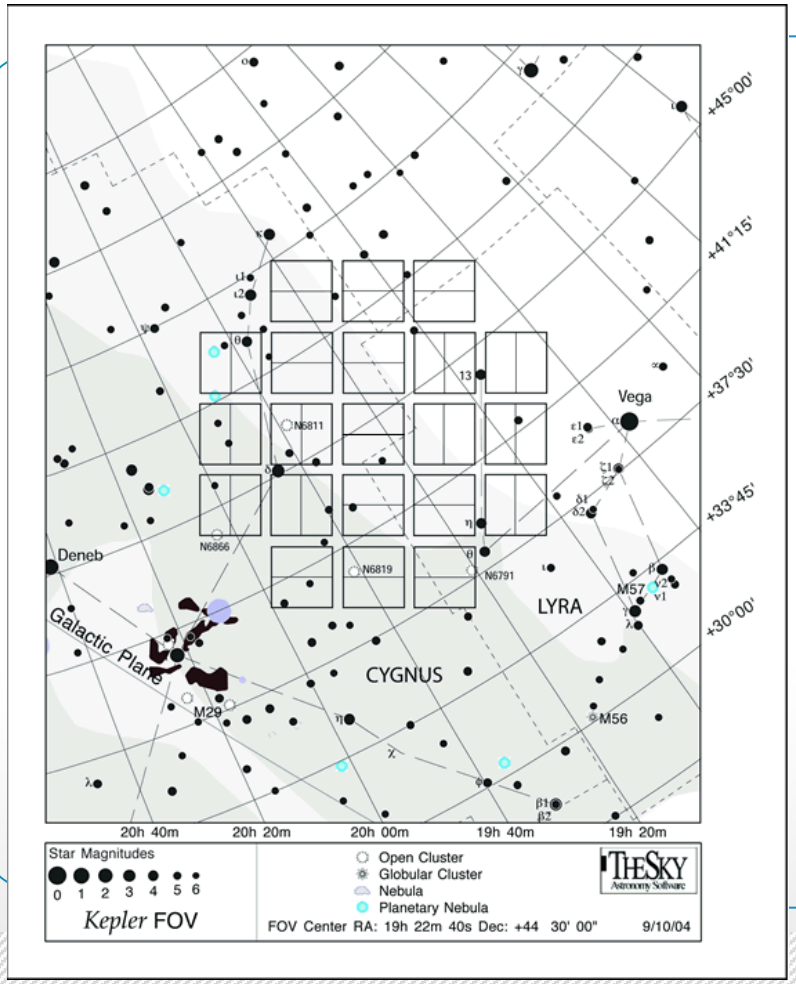
$$\tau_{cool} = 6.2 \times 10^4 \sim 3.1 \times 10^6 s$$

Table 2
The Estimated Parameters of the Flares

Parameters	STV	IDV
Duration Time T (s)	$2.1 \times 10^5 \sim 4.8 \times 10^6$	$5.9 \times 10^3 \sim 6.9 \times 10^4$
Median of Duration Time T_m(s)	1.1×10^6	2.6×10^4
Light Travel Time T_j(s)	$8.0 \times 10^5 \sim 1.1 \times 10^8$	$2.2 \times 10^4 \sim 1.6 \times 10^6$
Peak Flux F_p(mJy)	$3.8 \sim 56.1$	$4.3 \sim 37$
Median of Peak Flux f_m(mJy)	13.7	10.9
Emission Size R (cm)	$2.4 \times 10^{16} \sim 3.3 \times 10^{18}$	$6.6 \times 10^{14} \sim 4.8 \times 10^{16}$

The symmetric nature of the observed flares indicates that the skewness profiles can not just explained by a disturbance through the emission region or crossing time effect, light travel time effect. Meanwhile it may also be constrained by geometric effect and other effects.

Kepler blazar sources



Information:

- **Very good time coverage**
- **0.95-meter aperture**

BL Lac：

KIC 6690887--W2R 1926+42

KIC 7175757--5BZBJ1848+4245

Multiband analysis

P2-03	A Multiwavelength Study of Mrk 421	Xu Chen (Shandong U.)
P2-04	Spectral and correlation analysis of multiple wavelength for blazar PMN J2345-1555	Yunguo Jiang (Shandong U.)

WEBT observations

A&A 558, A92 (2013)
DOI: 10.1051/0004-6361/201220236

The 72-h WEBT microv of blazar S5 071

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Received 15 August 2012

ABSTR

Context. The international Whole Earth Blazar Telescope (WEBT) conse observations of S5 0716+714 from February 22, 2009 to February 25, 20 its high declination, and its very large duty cycle for micro-variations.
Aims. We report here on the long continuous optical micro-variability ligh during which the Blazar showed almost constant variability over a 0.5 n Observations from participating observatories were corrected for instrum curve.
Methods. Thirty-six observatories in sixteen countries participated in this compilation into a continuous light curve. The light curve was analyzed u analysis techniques. Those results led us to model the light curve by attrib
Results. We have interpreted the observed microvariations in this extende pulses due to cells in a turbulent jet which are energized by a passing shoc fit to the 72-hour light curve with the synchrotron pulse model.

Key words. quasars: individual: S5 0716+714 – BL Lacertae objects: inc

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Advance Access publication 2017 May 4

Radio and optical intra-day variability observations of five blazars

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MULTIFREQUENCY PHOTO-POLARIMETRIC WEBT OBSERVATION CAMPAIGN ON THE BLAZAR S5 0716 +714: SOURCE MICROVARIABILITY AND SEARCH FOR CHARACTERISTIC TIMESCALES*

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Welcome to visit Weihai observatory

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Thank you for your attention!